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Study Design Assessment for Waterfowl Production Surveys on Tetlin NWR

Jonathan Greenberg and Joel Reynolds

Division of Realty & Natural Resources
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STUDY DESIGN ASSESSMENT FOR WATERFOWL PRODUCTION SURVEYS ON TETLIN NATIONAL WILDLIFE REFUGE

Jonathan J. Greenberg and Joel H. Reynolds

Abstract

Tetlin National Wildlife Refuge monitors waterfowl brood production every year. The same eleven clusters of water bodies have been observed each year since 1985. Given the constraints on personnel, time, and budgets, it is imperative that brood production surveys be conducted efficiently in terms of both choice of sampling design and choice of sampling effort. We review the current survey design, identify statistical issues, and recommend potential solutions. Major topics include the lack of a clearly defined target universe and sample frame, measurement issues (focusing on survey timing and within season mortality), and minimum sample size required to achieve desired level of precision in brood production estimates. The study concludes with a series of recommended tasks that the Refuge should undertake to improve the brood survey's efficiency and effectiveness.

Introduction

Tetlin National Wildlife Refuge was established in 1980 predominately for conservation of waterfowl (http://tetlin.fws.gov/establishment.htm, accessed on 6/22/10). Aerial surveys and ground transect surveys of waterfowl production were conducted throughout the 1980s to develop a survey protocol within the constraints of the Refuge's size, staffing, and budget (Doyle 1990). In the late 1980's and early 1990's there was an effort to standardize the waterfowl production surveys with the management objective of detecting "major population changes on the order of 25% with 95% certainty" (Rogers 1987).

We review the current survey design protocol of the waterfowl productivity survey ('brood survey'). The review aims to (i) recast the survey into Region 7's draft I&M Protocol framework and terminology, (ii) identify unclear or missing survey design components, (iii) identify sources of potential statistical problems of bias or imprecision, (iv) where possible, use historic survey data to estimate the magnitude of each of these problems, assess their importance or suggest tasks that should be conducted to guide protocol revision, and (v) suggest potential resolutions or design considerations for future surveys.

Protocol Assessment

Objectives

Management Objectives

The stated management objective is to detect "major population changes on the order of 25% with 95% certainty" (Rogers 1987). The motivations for detecting major population changes were to provide information for setting harvest regulations and to provide a red flag for (potentially local) environmental distress. However, as currently phrased, this objective is too vague.

Monitoring objectives need to be *s.m.a.r.t.* (Williams et al. 2007): *specific* and unambiguous, *measurable* with appropriate field data, *achievable*, *results*-oriented, and applicable over the relevant *time*-frame. The species of interest, time-scale of interest, type of change (smooth vrs sudden shift, etc.), and acceptable Type I and Type II error rates should all be explicitly defined before any other action is taken. For example, a more clearly stated management objective would be "detecting an average annual decline of 8.825% over a 5-year period (corresponding to a total decline of 35%)[1] in Bufflehead density on Tetlin NWR with significance level of 10% and 80% power." This level of specificity is required to determine appropriate choices for all the other survey components and, ultimately, to determine the level of survey effort required to achieve the management objectives.

The type of change you want to detect (sudden change, smooth trend, etc…) must be specified to determine the desired analyses, which in turn must be defined before one can conduct sample size investigations. Identifying the intended analyses is required also to identify relevant covariates (if any) that should be measured each season (discussed below).

Species of Interest

The species currently being studied are divided into two guilds, dabblers and divers (Table 1). Not all species occur with sufficient frequency or at high enough abundance to support adequately precise summarization and analysis. Canvasbacks, Blue-winged Teals, Northern Pintails, and Northern Shovelers average less than 6 broods observed per year across all 11 water body clusters (Table 1, Figures 1 & 2). Given these low abundance levels, it is impossible to conduct meaningfully precise analysis or to assess decreases in abundance with adequate precision. Further, while observations are recorded for Scoter and Goldeneye species, there are no field protocols to determine age class, limiting the usefulness of the existing observations (see discussion of mortality, below). The rest of this report focuses on the remaining six species (denoted by '*' in Table 1).

Recommendations:

If the refined management objectives require information on Canvasbacks, Blue-winged Teals, etc., then further studies should be conducted in other regions of the refuge or other times of the season to determine if those species occur at an adequate density anywhere on the Refuge, and if so, when. Then the survey's sample frame and sample selection (discussed below) should be revised to include those places/time periods. This may require conducting a second brood survey.

Measured Attributes

The species, brood age class, and number of young are recorded for each detected brood in each surveyed water body. In addition, the water level of each water body is recorded on a qualitative scale from 1 to 5 (1 representing flood stage water levels, 5 representing dry shorelines).

[1] Population Model: $N_{t+1}=\lambda * N_t$

Covariates: water level
Water level measurements are subjective and could vary significantly between observers. As a consequence, historical water level figures may be difficult to interpret. Further, such ordinal measurement scales are difficult to incorporate into analysis. Water level measurements are not currently being used in any calculations.

Recommendations:
For each of the species, for each response of interest (average number of broods per cluster per year, average number of clusters occupied per year, etc.) analyze the variation explained by the covariate water level.[2] If a significant amount of variation is explained by water level, then consider developing a quantitative measurement protocol to standardize measurements across observers and survey seasons. Possible measurement protocols include measuring the water depth at predetermined locations or remotely sensing water body surface area at a particular date each season.

Other Covariates
No other covariates are currently being recorded besides water level. The study of potential covariates merits further consideration as they might help explain variation in the quantity(-ies) of interest, and thus lead to more precise estimates of brood production, occurrence, and hatch timing.

Recommendations:
Relevant literature should be reviewed to identify potentially useful covariates for each quantity of interest. Develop a conceptual model of the major drivers or influences on each quantity; these will be the potential covariates. Consider (i) characteristics at the water body level which may explain variation from water body to water body in species occupancy, brood occurrence, brood numbers, brood size, or hatch timing and (ii) characteristics at the Refuge level (or larger) that may explain variation from year to year in mean production or mean hatch timing.

Note that in order to be used to make inference to all clusters in the Refuge, a covariate would have to be *collected* across all clusters in the Refuge (see discussion of ratio estimators, below). This may imply restricting consideration to 'Refuge level' covariates that are easily measured each season (remote sensing?), or physical parameters on each water body that are expected to remain fairly consistent for a number of years after measurement. Potential covariates should then be regularly incorporated into future surveys for investigation. This will likely be an on-going process requiring focused consideration across many surveys.

Survey Design
Sample Units
The sample unit is a cluster of water bodies within a geographic area that satisfies certain implicit constraints.

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[2] Since water level is measured at the scale of the water body, yet the sample unit is the cluster of water bodies, analysis requires fitting a *mixed effects* or *random effects* model (different names, same concept) for each response of interest for each species of interest. The model should have a random effect for cluster and a set of orthogonal polynomial contrasts on the ordinal 'water level' covariate.

Recommendation:
Those constraints need to be fully defined in order to define the sample frame (see below) and thus the statistical population one can draw inference for. Presumably, there are implicit size constraints (i.e. between 0.5 and 5 water acres) as well as logistical constraints (i.e. searchable in 1 day).

Target Universe
The target universe is the set of items of interest we wish to learn about. There are both spatial and temporal dimensions to the target universe. Currently, the target universe is implicitly defined to be 'all water bodies within Tetlin NWR'.

We have many options for the spatial component of the target universe:

a) the 11 clusters of water bodies currently being surveyed
b) the accessible clusters within Tetlin NWR (must be explicitly defined)
c) all clusters of water bodies on Tetlin NWR (must be explicitly defined)
d) all water bodies on Tetlin NWR (the current, implicit target universe)

A precise definition of the target universe is required to allow clarification of any potential assumptions inherent in viewing the sample frame (below) as representative of the desired target universe. For example, the size constraints on water bodies considered for inclusion in clusters (see 'Sample Units') will eliminate from survey consideration all water bodies that are too small or too large. Similarly, the sample unit definition will exclude water bodies that are too isolated spatially.

Clarifying these issues will allow the biologist to consider, and if necessary, investigate potential biases stemming from these operational constraints (*frame errors* in the statistical survey literature). For example, if some waterfowl species preferentially inhabit or avoid particularly large water bodies (too large to survey in a day), then the survey estimates will be biased estimates for that species for the whole refuge (respectively underestimating or overestimating broods, young, etc…)

Recommendations:
All of the clusters of water bodies in the target universe (Tetlin NWR) should be identified and labeled on a map. The accessible/inaccessible clusters should similarly be distinguished and labeled.

Sample Frame
The sample frame is the collection of sample units actually available for sampling. Initial consideration was given to all sample units (e.g. 'right sized' water body clusters) accessible by foot, boat, or floatplane (Doyle 1990). Approximately 40% of the 'area' in Tetlin NWR could not be accessed by those means (ibid), immediately raising a potential concern for bias if waterfowl abundance and productivity systematically differ on the non-accessible water bodies versus the accessible water bodies.

A precise definition of the sample frame is required to clarify the inferences being drawn as well as potential sources of error (specifically, bias) in those inferences. For example, if the 11 clusters of water bodies currently surveyed are chosen as the sample frame, then all subsequent statistical inference applies only to those 11 clusters and not Tetlin as a whole; further extrapolation must be based on something other than statistical sampling.

Recommendations:
After clarifying the limnological and logistic constraints on a sample unit, and specifying the full sample frame, conduct some basic GIS analyses to:

(i) Reassess the percentage of Refuge surface area captured by the sample frame (hence what percentage of the target universe is unavailable for surveying). Previous studies in the late 1980's calculated that 60% of the Refuge surface area was captured by the sample frame (Doyle 1990).
(ii) Reassess the percentage of Refuge water acreage captured by the sample frame. Previous studies calculated that approximately 2% of the Refuge water acreage was captured by the selected sample (Unpublished data files[3])
(iii) Calculate the percentage of Refuge water bodies captured by the sample frame.

Potential Frame Changes
Water bodies in Tetlin NWR will likely undergo long-term change in shape and size due to changing environmental factors (Riordan 2006). Because of this potential for long-term temporal change in the sample units, the properties of the sample units in the sample frame (e.g. number of water bodies in each cluster, water acres in each water body, etc…) should be reassessed regularly and the sample frame updated (i.e. Once a decade? Every two decades?). These quantities are relied on in the analysis for the extrapolation calculations, so inaccuracies have potentially severe ramifications.

For example, current extrapolation from the surveyed clusters to the whole Refuge assumes that water body surface area has remained relatively constant since it was calculated in the late 1980s based on USGS topographic maps first created in 1955.

Recommendations:
Re-measure the size and shape of the water bodies in all sample units on Tetlin NWR using current or at least more recent imagery or aerial photography. The year of imagery data collection should be recorded as part of the protocol. Ideally, the same information source would be used each time so as to eliminate changes in mapping accuracy from using different sources. This undertaking will require significant thought due to the within-season changes in surface water level. The process should be repeated every decade or as dictated by the rate of change of water bodies and their surface dimensions.

Frame Definition (Spatial)
There are at least two options for defining the spatial dimensions of the current sample frame:

(i) Sample Frame = all accessible sample units

[3] Unpublished calculation notes on yellow legal sized paper from the waterfowl brood survey files of Tetlin NWR.

In this case we have no idea how the 11 currently observed clusters are related to the sample frame, eliminating the possibility of any assumption-free statistical inference from the sample to the full frame.

(ii) Sample Frame = the 11 currently observed clusters
In this case we have a census of the frame and it is clear that any extrapolation from the sample frame to the target universe requires a number of major rhetorical assumptions.

Option 1 is recommended to avoid future confusion in interpreting the extrapolations made during analysis of existing data, as well as to encourage consideration of revisiting the sample selection.

Frame Definition (Temporal)
After investigations in the 1980s regarding hatch timing, it was decided that a single survey conducted between early and mid-July(?) would adequately capture both dabbler and diver broods (Figure 3). The current survey tends to capture Mallards that are predominantly age class II or III and Scaup that are almost exclusively age class I (Figure 4 a,b).

If there is a systematic shift in hatch dates, then the Refuge will need to consider modifying survey timing to accommodate this shift. Alternatively, if within season variation in hatch date is increasing for a species, or if the current level of correlation in mean hatch dates between the main species declines (e.g., breakdown of lagged synchronicity among Mallards and Scaup) (Figure 5), then the Refuge will need to consider conducting two surveys per season. This topic is discussed in more detail under Measurement & Survey Timing.

Sampling Designs
The implicitly defined target universe is all the water body clusters in Tetlin NWR. The current sample frame is all accessible water body clusters. Eleven clusters are surveyed every year (Table 2). The validity of any inference from the eleven observed clusters to the unobserved clusters forming the rest of sample frame depends on the relationship between these two sets. That relationship is determined by how the sample was selected.

The eleven clusters were selected subjectively in an attempt to represent the variety of habitats present on Tetlin NWR (Doyle 1990). There does not appear to have been any probabilistic selection of clusters from the sample frame, eliminating the possibility of any assumption-free statistical inference based on the design. This raises concerns over *bias* (there is no statistical basis for treating summaries from the sample as unbiased estimates of the true value over the rest of the sample frame) and over the *absence* of any assumption-free basis for estimating *uncertainty* of the summaries.

The spatial layout (Figure 6) and documentation (Doyle 1990) suggest the intention to provide systematic coverage of the Refuge and/or clusters in each of three strata (see below). However, treating the clusters as if they were a stratified simple random sample for analyses must be done with the realization that this rests on a very large assumption. The possible magnitude of this assumption could be assessed in two different ways.

(i) Qualitative: Identify all of the accessible sample units in Tetlin NWR (Sample Frame option 1). Determine the total number of water bodies and total number of water acres. Calculate the percentage of water bodies and the percentage of water acres contained in the 11 surveyed clusters. Previous studies calculated that approximately 2% of the Refuge water acreage (1313 acres out of 65159.2 total acres) was captured by the selected sample (unpublished data files), so *assuming* representativeness is a big assumption.

(ii) Quantitative: Using a sample frame of all accessible sample units in Tetlin, randomly select X sample units and begin surveying both the 11 and the new simple random sample of X sample units. Repeat this for a number of years, then assess differences between the average estimates from the eleven clusters versus the X clusters and develop a calibration method for relating the eleven clusters to all the accessible clusters.

Stratification

The Tetlin NWR was stratified into 3 levels (high, medium, and low) based on presumed waterfowl productivity (Table 2) (Doyle 1990). It appears that geographic considerations and qualitative productivity numbers were used in defining the strata (Figure 6).

The current stratification does not improve estimation precision. A cluster's membership in a stratum is constant across species and through time, but the cluster's productivity varies with species and through time, widely in most clusters (Figures 7-12). For example, Scaup productivity on cluster 10 (34 Lake) has rapidly declined from 196 young in 1993 to 26 young in 2009 (Figure 12). Thus, the benefits of stratification are not consistent through time.

Recommendations:

The medium and low strata should be combined since (i) you need at least three clusters in a strata to estimate a strata variance (Low currently only has two clusters), and (ii) for most species, these strata are nearly indistinguishable in any year (Figure 13), suggesting that estimating separate means and standard errors for these strata provides no precision 'gain' to offset the estimation 'cost' (reducing the degrees of freedom in the overall standard error estimates). These issues make the current stratification irrelevant at best. It should be abandoned to avoid wasting effort and unnecessarily complicating the analysis.

Cluster Sampling

Clusters of water bodies are currently being used as the sample units at Tetlin NWR. Cluster sampling was chosen to maximize data collection efficiency (Tetlin Manager 1985). Surveying clusters as sample units appeared to be the most logistically efficient method in terms of the number of water bodies surveyed per person day (McDonald 1989).

Recommendations:

As mentioned previously, the definition of a cluster needs to be precisely defined. Ideally, logistical constraints for clusters should be defined (i.e. searchable in 1 day), as well as size constraints for feasible water bodies (i.e. between 0.5 and 5 water acres). A precise definition of sample units/clusters is required to fully define the sample frame and thus the population one can draw statistical inference for.

Monitoring Design

Repeating the waterfowl brood survey across years raises two other design questions: (i) how frequently should the survey be conducted? Annually? Bi-annually? etc., and (ii) how should clusters be selected for measurement each survey?

Survey Frequency

Survey frequency will depend on both the monitoring objectives and the survey's priority and cost relative to the other elements in Tetlin NWR's biological program. If the objective focuses on long-term patterns of change, then consideration should be given to conducting the survey every second or third year. Statistical planning analyses could be conducted to assess the tradeoff among different monitoring frequency plans (see, for example, Reynolds *in Review*). This will be untenable for objective aspects focused on annual production.

Survey Selection

There is a spectrum of monitoring designs controlling how clusters are selected each survey. At one extreme is a *cross-sectional* design where a completely new sample of clusters is selected each survey. This design results in simpler analyses of net change since all samples are selected independently in time and, in time, allows full exploration of the sample frame. However, it can be less efficient for detecting net change than those discussed below as it includes variability from both net change within a sample unit, the primary focus of interest, and change through time in sample unit selections, a source of noise (Duncan and Kalton 1987, Fuller 1999). Information on gross change within a sample unit is only provided by chance when a unit is randomly revisited.

Alternatively, a *panel* design selects a set of sample units once and then restricts all future observation to those units (Duncan and Kalton 1987, Overton and Stehman 1996, McDonald 2003). If attribute measurements from the same unit at different times are positively correlated, then this design provides the most precise estimates of net change or trend, allows estimation of gross change, and minimizes design planning and effort since these only have to occur once (McDonald 2003).

However, a pure panel design is subject to problems if (i) new sample units are added to the frame as time passes, since these units were unavailable for selection in the initial panel, or (ii) units drop from the frame as time passes, potentially causing the panel to shrink. For example, monitoring just the eleven current clusters may cause problems, over the course of decades, if water bodies in those clusters eventually fill in and shrink or disappear. In the extreme, some of the clusters may cease to exist. Proper analysis of a pure panel design is also more complicated since it requires accounting for dependence in repeated measurements from the same sample unit.

Alternative monitoring designs have been developed that retain some of the statistical power for change detection of a pure panel design while also providing the population coverage and efficient status estimation of cross-sectional designs: rotating panel designs, serially alternating panels, augmented panel designs, etc. (Duncan and Kalton 1987, Urquhart 1998, 1999, McDonald 2003). These ideas are built around having a portion of the samples taken at any one time be repeat visits to previously sampled sites and the rest being newly sampled sites.

Analysis is much more complicated and generally requires active participation by a statistician since every sample consists of units that have never been revisited and units that have (Schreuder 1993:178-182; Urquhart 1998). Depending on the design, those units that have been revisited may differ in the number of revisits and their temporal spacing. While the 'current' cross-sectional population status can be estimated as if it is just a single sample, more precise estimation of status can be achieved by incorporating information from previous visits (Schreuder 1993:183-188). Efficiently estimating change involves numerically fitting models that explicitly account for dependence among observations from the same unit.

Monitoring design options include:

a) <u>Select the same eleven clusters every time (panel)</u>
   The advantage of this approach is that the data gathered over the past 20 years can be used in any analysis. The main disadvantage of this method is that although the relative percentage of all feasible clusters can now be determined, this sample has still been selected subjectively and cannot be assumed to be representative of the entire sample frame. Any further inference or extrapolation will include unknown bias.
b) <u>Randomly select new clusters every time (cross-section)</u>
   The advantage of this approach is that the randomly selected clusters will be representative of the sample frame and can be used for statistically valid inference and extrapolation. However, if this method is used then it will still be impossible to make useful inference/extrapolation from the previous 20 years of data.

Recommendations:
Use the historic data to estimate the variance contribution (for each quantity of interest) from the within cluster-, between-cluster, and between-cluster x year interaction components. This would allow one to assess the precision gains expected for estimating trend from a pure-panel or hybrid monitoring design versus a cross-sectional design.

If feasible, each year survey the 'historic' eleven clusters *and* a random selection of new clusters. Doing this for five to ten years would allow one to develop a calibration between the eleven clusters and the rest of the sample frame, hopefully allowing one to use the historic data in trend analyses yet shift to a statistically valid sample selection process. Eventually, the 'eleven' could be dropped and sampling focused on the randomly selected clusters. The random selection should follow whatever recommendations were drawn from the variance component analysis mentioned above (i.e., cross-sectional or panel or hybrid?).

Measurement Issues
The brood survey's measurement process raises a number of issues of potentially great importance with regard to bias and/or confounding.

Flushing/Brood Detection
Flushing style (how far away from the edge of the water body the assistant walks to flush broods) differs between observers. This is a possible additional source of random variation.

This could be resolved by clarifying the protocol document regarding how the flushing should be done and conducting brief in-field training sessions each year. Ideally, the same path is followed each year.

Species Identification, Brood Count, Age Class Assignment
These measurements all seem fairly accurate, but the prevalence/effect of misidentification or miscounting has not been measured or accounted for in the current calculations. There is a potential for failure to detect all broods, or all young, but this could not be assessed using existing data. Consideration should be given to undertaking a specific study to explore this issue.

Non-response
Sometimes water bodies are unreachable (due to logjams, weather, etc…) and consequently no birds are recorded at those locations. It is important that the final dataset differentiate those lakes that have no waterfowl present in a year from those lakes that weren't surveyed. These two scenarios (0's and NA's, respectively) are treated differently in the analysis.

Mortality
Waterfowl mortality is very difficult to measure and existing studies have shown mortality to be highly variable across environments, years, etc. (Baldassarre 2006). The simplest approximation of mortality at Tetlin comes from assessing changes in the average number of young per brood across each age class (Figure 14). However, this does not provide an accurate picture of actual mortality. The mortality rate will be biased low because of (i) the inability to account for losses of entire broods, (ii) the inability to account for losses of some older (near fledging age) young (Batt 1992) and (iii) the possibility that a large proportion of the brood predation may have occurred before the brood was first counted.

Ideally, one is interested in the number of flight-ready (fledged) waterfowl produced by each species each year. However, three difficulties arise from within season mortality and its relationship to survey timing.

(1) Surveys have to be conducted before fledging and counted birds may still die before fledging due to predation, exposure to the elements, etc... This causes overestimation of the number of fledged birds for each species. This bias may be small for birds of older age classes (II/III), but could be a relatively large for young birds (age class I). I.e. a brood of 10 class III birds will likely result in more fledged birds than a brood of 10 class IA birds, but in either case the number of fledged birds is only known to be ≤ 10. This problem will be especially problematic for divers (Figure 4a,b).
(2) Surveys conducted before all broods of a species are born would underestimate the number of fledged birds for that species. This problem will be especially problematic for divers (Figure 3, 4b).
(3) For each species, the relative impact of both biases will vary across years as the timing of the survey changes with respect to that year's breeding phenology. This will cause confounding in any measurement of change, such as a fitted trend, due to the changing mix of observed age classes each season (Figures 4a,b).

Without knowledge of the relative magnitude of each of these biases, and their variation across years (for each species), the total number of young observed is difficult to interpret. If bias 2 dominates, then the total number of fledged young will be underestimated. If bias 1 dominates, then the total number of fledged young will be overestimated.

Furthermore, each species' observed age class distribution varies across years (Figures 4a,b) due to variation in hatch date (Figure 3). Buffleheads are a good example, exhibiting some years when approximately 90% of the broods surveyed were in class I and other years when 90% of the broods surveyed were in class II. This creastes a very high potential for the overall bias to change from year to year and make uninterpretable any trend or change estimation based on the total number of young observed.

Lacking species-specific mortality rate data by age class from Tetlin NWR, the potential impact of these biases might best be resolved as follows:

Option 1: A brood has a much higher probability of survival to fledging than does a duckling (Figure 15) and therefore is much less susceptible to these measurement bias issues. Therefore one resolution is to make the main response variable the number of broods not the number of young. Focusing on the number of broods allows a brood with 10 class 1A young to be counted as equal to a brood with 4 class 2C young.

Option 2: Use the literature (e.g., Batt 1992) to estimate the average number of young fledged per brood for each species and use that to approximate the number of fledged young produced at Tetlin NWR each year. However, this would entail assuming a constant 'fledged brood size' for a given species rather than year-specific values. Thus the expansion would not account for year to year variation and so wouldn't alter any estimates of change or trend from those based directly on number of broods per year.

An alternative approach for accounting for within season mortality in the analysis is discussed below in the next section.

Survey Timing

This issue is closely linked to the mortality issue. If (i) survey timing is not consistent with respect to a species' mean hatch timing, or (ii) variation in hatch date among broods changes across years, then observed age class distribution will change across years and cause confounding with any actual changes in a species' number of broods or fledged young produced. For example, if one year the survey is timed to catch Mallard young in their IA stage it will likely record a very large number of young. However, if the next year the survey catches Mallard young in their III stage there will be many fewer young (and perhaps slightly fewer broods). Mallard production has not necessarily declined; rather, the lower production number results from the survey occurring later developmentally (and subsequently counting a different age class distribution). The goal should be to time surveys so the brood age class distribution is consistent across years for a species; this is likely impossible to achieve in practice.

Accounting for Survey Timing/Mortality Issues
The problem of varying age class distribution can be approached either by modifying the experimental design or by modifying the analysis. Some possible modifications under both approaches are given below.

Design Modification Suggestions:
1. (Ideal) Time the survey to observe each brood on the day before they fledge. This would eliminate most of the mortality issues. This would only be feasible, for a particular species, if they exhibit very little brood-to-brood variation in hatch date and hatch date could be accurately and precisely predicted beforehand each season. The historical data suggests that there is significant brood-to-brood variation in hatch dates (Figure 3), making it difficult to eliminate mortality issues by modifying the survey design.

2. Develop a model for predicting when to time the survey each year.
a. Analyze each species' mean (or median) hatch date each season, as well as variation among broods in hatching dates each season, and try to develop predictive models for each. Review the literature and identify environmental drivers or other factors potentially influencing hatch date for each species, then assess their ability to predict the annual mean hatch date, etc.

For example, current efforts to predict mean hatch date using May temperature records from the Tetlin airport should be expanded to assess (at least) six different temperature formulations: mean May hourly temperature, mean mid-April to mid-May hourly temperature, cumulative degree days (hours?) above freezing from 1 April to end of April, to mid-May, to end of May, and to mid-June. Fit a generalized additive model, or a linear model using a spline representation of the temperature predictor to capture potential nonlinear relations (Harrell 2001), for each predictor, then use AIC (Burnham and Anderson 2002) to identify the best predictor.

b. Many species exhibit relatively highly correlated mean hatch dates, implying, for example, that an early hatch year for Mallards is similarly early for Scaup (Figure 5). This implies a consistency in the difference between their mean hatch dates. Ideally, thought should be given to developing a multivariate predictor from the 20+ years of brood-specific hatch date info, identifying both (i) 'later hatching' species that are adequately predictable from 'early hatching' species and, possibly, (ii) covariates that adequately predict the 'early hatching species'.[4] At minimum, consistent differences in mean hatch dates should be assessed. If consideration is given to conducting two surveys, then these differences could be used to predict the best timing for the later survey based on the hatch date information observed in the earlier survey.

Analysis Modification Suggestions:
1. Make the response variable the number of broods rather than the number of young. This will mask a lot of the mortality issues as broods are much less sensitive to mortality than young (Figure 15).

[4] Perhaps via consultant contract or as a Master's thesis project in Statsitics.

2. Use a model of within-season mortality to project the number of young observed in each age class to the expected number of fledged young.[5]

Mortality Modeling

Within season duckling mortality has the potential to bias waterfowl productivity estimates in Tetlin NWR. If a plausible model can be developed and fit, then the number of young in any age class can be converted to the number of expected fledged young. This conversion will account for the year-to-year changes in relative timing of the survey. Thus reducing variation in the number of young produced and also eliminating confounding related to varying age class distributions.

As an example, a simple model was developed to account for within season duckling mortality. The model assumes the user provides within season mortality rates, duckling age class, and species (to determine the duration of each age subclass). The mortality rate is split into (i) a "first hit" mortality representing the dominating mortality during the first 2 weeks of development, and (ii) a daily mortality rate representing mortality from two weeks to fledging. If the duckling is observed in age class IA or IB, then the "first hit" and the daily mortality rates are both applied to calculate the predicted number of fledged young. If the duckling is observed in age class IC or higher, then only the daily mortality rate is applied to calculate the predicted number of fledged young. Studies suggest that the "first hit" mortality rate should be between 75% and 95% of the overall within season mortality (Batt, 1992); the example model assumes a "first hit" mortality rate of 85%.

This model was applied to the historical data with three different within season mortality rates: 65%, 85%, and 95%. As expected, the number of observed young are uniformly greater than the predicted number of fledged young (Figures 16-18). The decrease is not constant across species – the conversion from observed young to predicted fledged young has a much greater impact (Figures 19-21) on later hatching species, e.g. divers (Figure 3). Dabblers are generally observed after age class IB and thus after the "first hit" mortality (Figure 12a, b), so their observed numbers are fairly close to their predicted numbers (Figures 16-21). Diver broods hatch later, thus more young are observed at the IA or IB age class, thus there is a greater mortality modification to get to the predicting number of fledged young (Figures 16-21).

Note that since the predicted number of fledged young will be less than or equal to the number observed, the residual variation from fitting a trend model to the predicted number fledged will be less than or equal to the residual variation from fitting a trend model to the number of observed young (see demonstration results for Ring-Necked Ducks and Scaup in Table 3). Smaller residual variation will enable a more powerful assessment of the long-term trends in waterfowl production.

Recommendations:

The current mortality model is very simple and relies on large assumptions. Refining the model and validating it with local studies would allow for more accurate and precise estimates of mortality and, consequently, waterfowl production.

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[5] Perhaps via consultant contract or as a Master's thesis project in Statsitics.

If the model is deemed adequate then it could be be used to reduce confounding from variation in relative survey timing. Ideally, the model should be fit to each species' brood size and age data to develop Tetlin-specific mortality rates.[6] If this proves feasible, then might allow for annual estimation of Tetlin-specific within-season mortality rates. At minimum, the model could be used with a plausible range of mortality rates to get a sense of the sensitivity of any trend assessment to the confounding from survey timing.

Analysis

Circularity in Extrapolation

In the original power analysis calculations it was necessary to determine the total number of clusters in the target universe. Although this number should be counted directly (as discussed previously), the total number of clusters was estimated by dividing the total water acreage of Tetlin NWR by the average water acreage of the sampled clusters. This approximation gives a biased estimate of the number of clusters in the (not yet fully defined) sample frame.

For example, if the eleven clusters sampled all had relatively small water acreage (perhaps the largest lakes were systematically excluded from the sample) then the average water acreage per cluster would underestimate the true value over the full sample frame. The total water acreage in Tetlin NWR would then be divided by this estimated average, overestimating the actual number of clusters in Tetlin NWR and subsequently biasing any further extrapolations.

Power Calculation Error (11 vs 17)

Although the DuckPop.xls power analysis spreadsheet was not explicitly used for this report, it is important to briefly discuss an error in the spreadsheet's calculations. The spreadsheet requires a value for the average cluster size for the population (Tetlin NWR). This value has been entered as an arbitrary 139.8 water acres/cluster without any justification. For the unstratified power analysis, this value should be estimated by the average cluster size of the selected sample: number of water acres sampled divided by the number of clusters sampled, which is 153.8 water acres *not* 139.8 water acres. This change affects the estimate for the number of clusters in the population and all subsequent variance calculations.

Ratio Estimators

In previous analyses, it was concluded that the correlation of number of broods per cluster and number of water bodies per cluster yielded a ratio estimator with more precision than the ratio estimator based on broods per surface area of water bodies (McDonald 1989). Consequently, the report recommended that all further calculations be done using water bodies as the denominator in a ratio estimator. It appears that this recommendation has not been utilized in the current analysis.

Recommendations:

Since this initial suggestion was made after analyzing only three years of data, the correlation calculations should be re-done using all twenty years of historic data. Whichever ratio estimator

[6] Perhaps via consultant contract or as a Master's thesis project in Statsitics.

covariate is found to be most effective (water bodies or water acreage) should then be used in all further analyses.

Survey Effort Requirements / Power Analysis / Sample Size Estimation
A power analysis is conducted for planning purposes to determine the minimum sample size required to meet stated precision goals. Currently, there are no fully specified management objectives motivating the survey, thus there are no explicitly defined precision requirements to be achieved by the monitoring effort. Consequently, there is no way to assess the adequacy of the current level of survey effort or provide guidance on the required level of effort. However, we've illustrated the process one would follow to conduct such calculations using the historic data. The actual calculations in this section rely on a variety of assumptions and should not be treated as recommendations.[7] The following results should be viewed strictly as 'proof of concept' and should not be used for guidance on survey effort levels.

Effort for Estimating Annual Brood Production
The first sample size estimation uses a single sample t-test to determine the number of clusters required to achieve a certain precision in estimating a species annual brood production. The results are presented in terms of the expected magnitude of the half-width of a 90% confidence interval for the number of broods per cluster (for each species) as a function of number of clusters sampled (Figures 22a,b). For reference, each species' average number of broods per cluster are given in Table 1. The sample sizes required for different confidence interval half-widths of the number of broods per water acre and broods per water body are also given (Figures 23a,b, 24a,b).

Lacking any specific management information objectives, arbitrary precision goals were used for illustration: confidence interval half widths of 0.75 broods/cluster, 0.0025 broods/water acre, and 0.05 broods/waterbody. To understand the relative precision of these values, species specific average results are in Table 1. The number of clusters required to meet these precision goals varied across species, but most were between 15 and 60 clusters (Figures 22a,b, 23a,b, 24a,b).

Effort for estimating minimum detectable change in brood production between two surveys
A two sample t-test was used to calculate the minimum sample size required to meet the precision goals for detecting a minimum level of change from one year to the next. The calculations assumed a Type I error rate of 0.10 and Type II error rate of 0.20 (equivalently, statistical power of 0.80). The minimum detectable difference between two years in mean number of broods per cluster is given in Figures 25a & b, in mean number of broods per water acre is given in Figures 26a & b, and in mean number of broods per water body is given in Figures 27a & b.

Lacking any specific management information objectives, arbitrary precision goals were used for illustration: minimum detectable differences of 0.75 broods/cluster, 0.0075 brood/water acre, and 0.05 brood/waterbody. To understand the relative precision of these values, species specific

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[7] Among others, the eleven surveyed clusters are assumed to be a simple random sample, the true number of clusters in the sample frame is assumed to be 424, and the number of water bodies and water acres in each cluster is assumed known (and constant across years).

average results are in Table 1. The number of clusters required to meet these precision goals varied across species, but most were between 25 and 100 clusters per year (Figures 25, 26, 27).

Note that these calculations are in terms of broods, not observed young or expected fledged young.

Suggestions/Conclusions

Specific recommendations from the study are provided, followed by a highlighted series of key observations.

Recommendations:

- Clearly define the management objectives
- List all water body clusters in the Tetlin NWR, establishing size and logistical constraints on water bodies and clusters
    - Determine the accessibility of all clusters and clearly define the sample frame
    - Calculate the percentage of inaccessible clusters to assess the magnitude of bias
    - Develop a protocol for the decadal re-measuring of water bodies and water acreage in the target universe
- Consider possible covariates for improving precision of brood production estimates
    - Examine the relationship between water level and brood production
- Modify data entry to differentiate 0 observed broods from not observing a water body
- Observe a random sample of clusters in addition to the 11 clusters currently selected in order to develop a calibration between the current sample and the target universe (apply this calibration to the historical data)
- Reassess the ratio estimator calculations using historical data and the actual number of clusters in the target universe
- Approximate brood/young within-season mortality in Tetlin and develop a model (similar to the one in this report) to account for it

Defining the management objectives and clarifying the target universe and sample frame should be the first recommendations implemented. Then the power analyses should be recalculated (with the corrected sample frame details) to determine the minimum sample size required to reach the precision goals. Those analyses will guide the decision to modify the survey further or discontinue it completely.

Important Observations:

- Stratification should not be used because clusters do not exhibit consistent production levels across time or across species.
- Clustered sampling is a cost-effective method of sampling for this application.
- The spatial component of the target universe should be defined as all clusters of water bodies in Tetlin NWR.
- The spatial component of the sample frame should be defined as all accessible clusters of water bodies in Tetlin NWR.
- Waterfowl production calculations should use number of broods (instead of number of young) because broods are less sensitive to mortality. This assumes that knowing brood

production rather than young production is adequate to meet the management information needs.

- Canvasbacks, Blue-winged Teals, Northern Pintails, and Northern Shovelers are not observed with sufficient frequency or abundance by the current survey to support summarization or analysis.

ACKNOWLEDGEMENTS

This survey design assessment would have been impossible without the patience, responsiveness, and dedication of Peter Keller and Bud Johnson, wildlife biologists, Tetlin NWR. This project was funded by Tetlin NWR and Region 7 of the National Wildlife Refuge System, Division of Realty and Natural Resources.

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Table 1. Waterfowl species regularly surveyed on Tetlin NWR, by guild. A species that, on average, occurs in over half of the clusters each year ('Average number of clusters occupied / year') and has a moderate number of detected broods per year ('Average Broods/Year') to potentially support detecting change in time are denoted by '*'.

Divers	**Avg. Broods/ Yr**	**Avg. Cluster Occ./Yr**	**Avg. Broods/ Cluster**	**Avg. Broods/ WB**	**Avg. Broods/ WA**
*Scaup (*Aythya affinis/marila*)	23.6	6.4	3.69	0.15	0.014
*Bufflehead (*Bucephala albeola*)	14.4	6.2	2.31	0.09	0.009
*Ring-necked Duck (*Ay. collaris*)	8.0	3.6	2.21	0.06	0.005
Canvasback (*Ay. valisineria*)	3.3	1.9	N/A	N/A	N/A
Surf Scoter (*Melanitta perspicillata*)	N/A	N/A	N/A	N/A	N/A
White-winged Scoter (*Mel. fusca*)	N/A	N/A	N/A	N/A	N/A
Goldeneye (*Buc. clangula/islandica*)	N/A	N/A	N/A	N/A	N/A
Dabblers					
*American Wigeon (*Anas americana*)	16.6	6.8	2.46	0.10	0.010
*Green-winged Teal (*An. crecca*)	13.4	5.8	2.31	0.09	0.008
*Mallard (*An. platyrhynchos*)	12.6	6.3	1.98	0.08	0.007
Northern Pintail (*An. acuta*)	5.3	3.4	N/A	N/A	N/A
Northern Shoveler (*An. clypeata*)	3.1	1.7	N/A	N/A	N/A
Blue-winged Teal (*An. discors*)	0.2	0.2	N/A	N/A	N/A

Table 2. Currently surveyed waterbody clusters in Tetlin NWR and their corresponding strata.

Cluster #	Cluster Name	Strata
1	Scottie Creek	High
2	Desper Creek	High
3	Peninsula Lake	Medium
4	Deadman Lake	Medium
5	Wellesley Lake	Medium
6	Landing Lake	Low
7	Square Lake	Medium
8	Tahamund Lake	Medium
9	Fish Camp Lake	High
10	34 Lake	High
11	Trail Lake	Low

Table 3. Point estimates and 90% confidence intervals for the linear trend in number of young vs. year under different mortality adjustments (rows), by species (column):observed, adjusted for overall mortality rate of 65%, 85%, and and 95%.

Species	**AGWT**	**AMWI**	**MALL**	**BUFF**	**RNDU**	**SCAU**
Raw	-2.32 (-3.34, -1.29)	1.03 (-0.28, 2.34)	1.48 (0.15, 2.82)	-0.26 (-1.03, 0.50)	-1.06 (-2.80, 0.66)	-0.71 (-5.46, 4.05)
Adj. 65%	-2.2 (-3.24, -1.16)	0.41 (-0.91, 1.73)	1.36 (0.10, 2.63)	-0.53 (-1.39, 0.33)	-1.07 (-2.25, 0.10)	-0.79 (-3.81, 2.23)
Adj. 85%	-2.17 (-3.24, -1.09)	0.24 (-1.09, 1.57)	1.33 (0.08, 2.57)	-0.60 (-1.51, 0.30)	-1.07 (-2.12, -0.03)	-0.81 (-3.43, 1.81)
Adj. 95%	-2.15 (-3.24, -1.05)	0.15 (-1.19, 1.49)	1.31 (0.08,2.54)	-0.64 (-1.57, 0.30)	-1.07 (-2.07, -0.07)	-0.82 (-3.27, 1.63)

Figure 1. Total number of broods observed across all waterbodies and clusters per year by species (panel). Very few BWTE, NOPI, NSHO, and CANV broods are observed under the current survey.

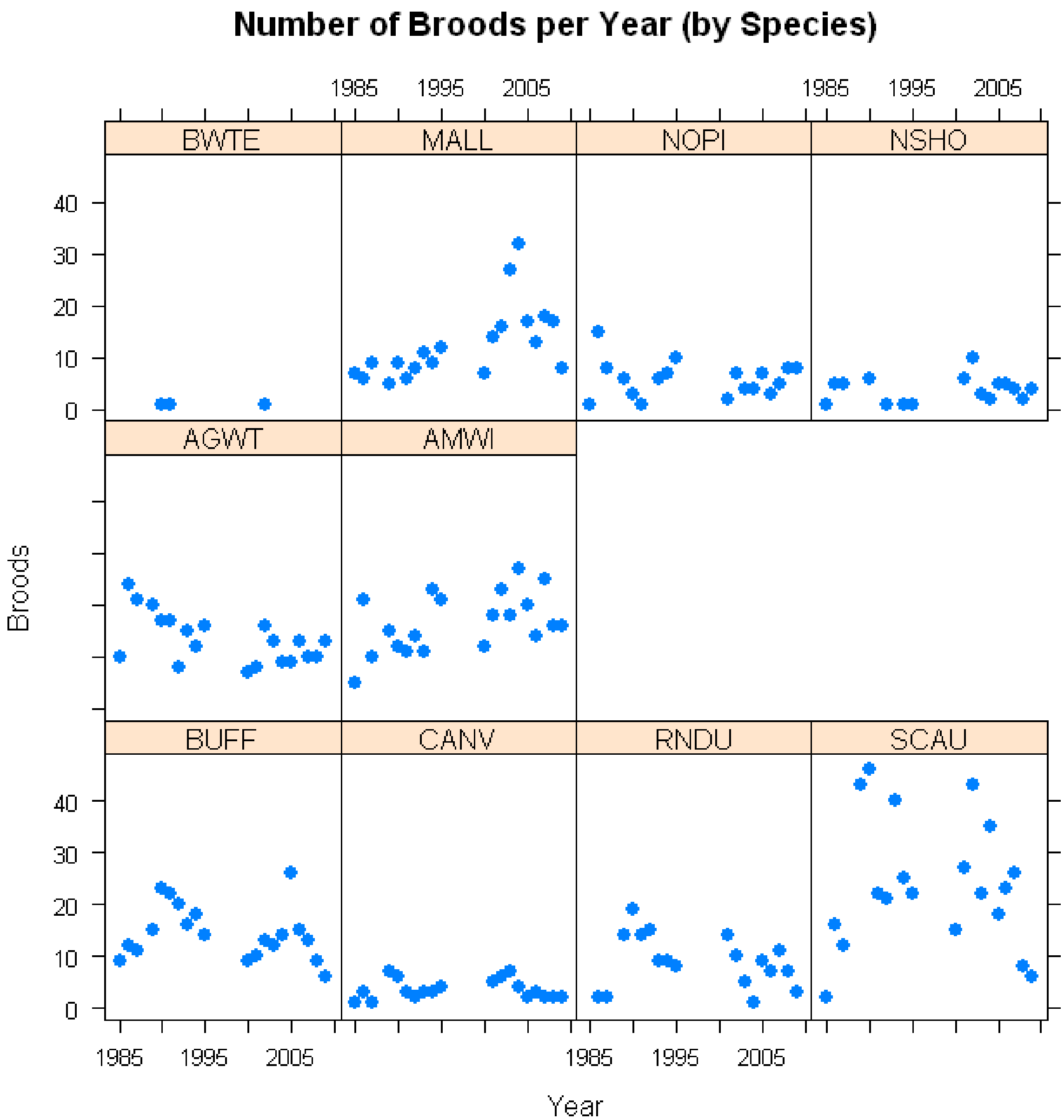

Figure 2. Species occurrence, by cluster (row) and year. BWTE, CANV, NOPI, and NSHO are not regularly observed.

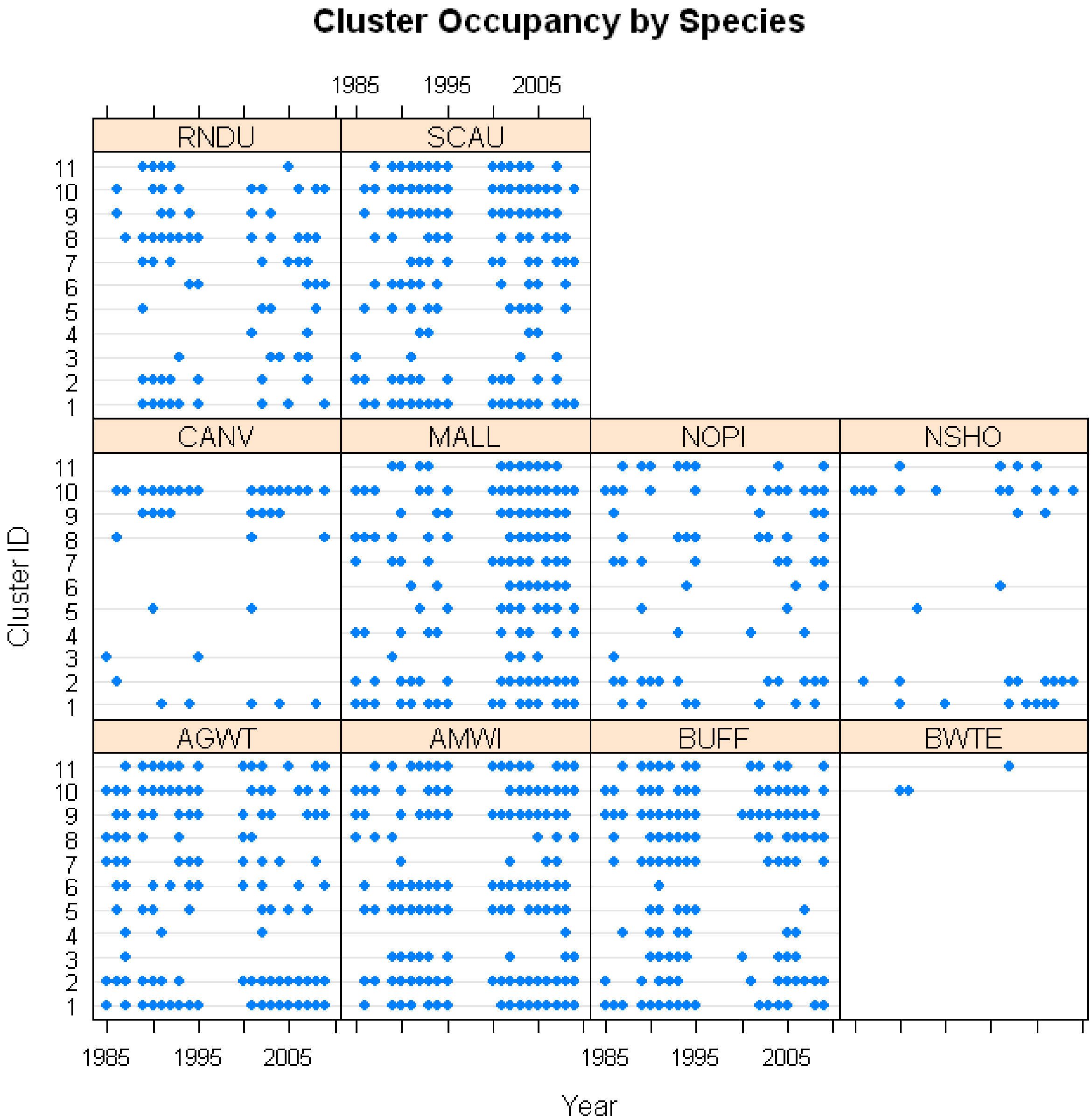

Figure 3. Distribution of estimated brood hatch date by year (row) and species (panel). The hatch date was estimated by backdating each brood based on its age class. Black circles mark the median hatch date observed that year. Hatch date varies among broods, across years, and across species, with dabblers (AGWT, AMWI, MALL) tending to hatch earlier than divers (BUFF, RNDU, SCAU).

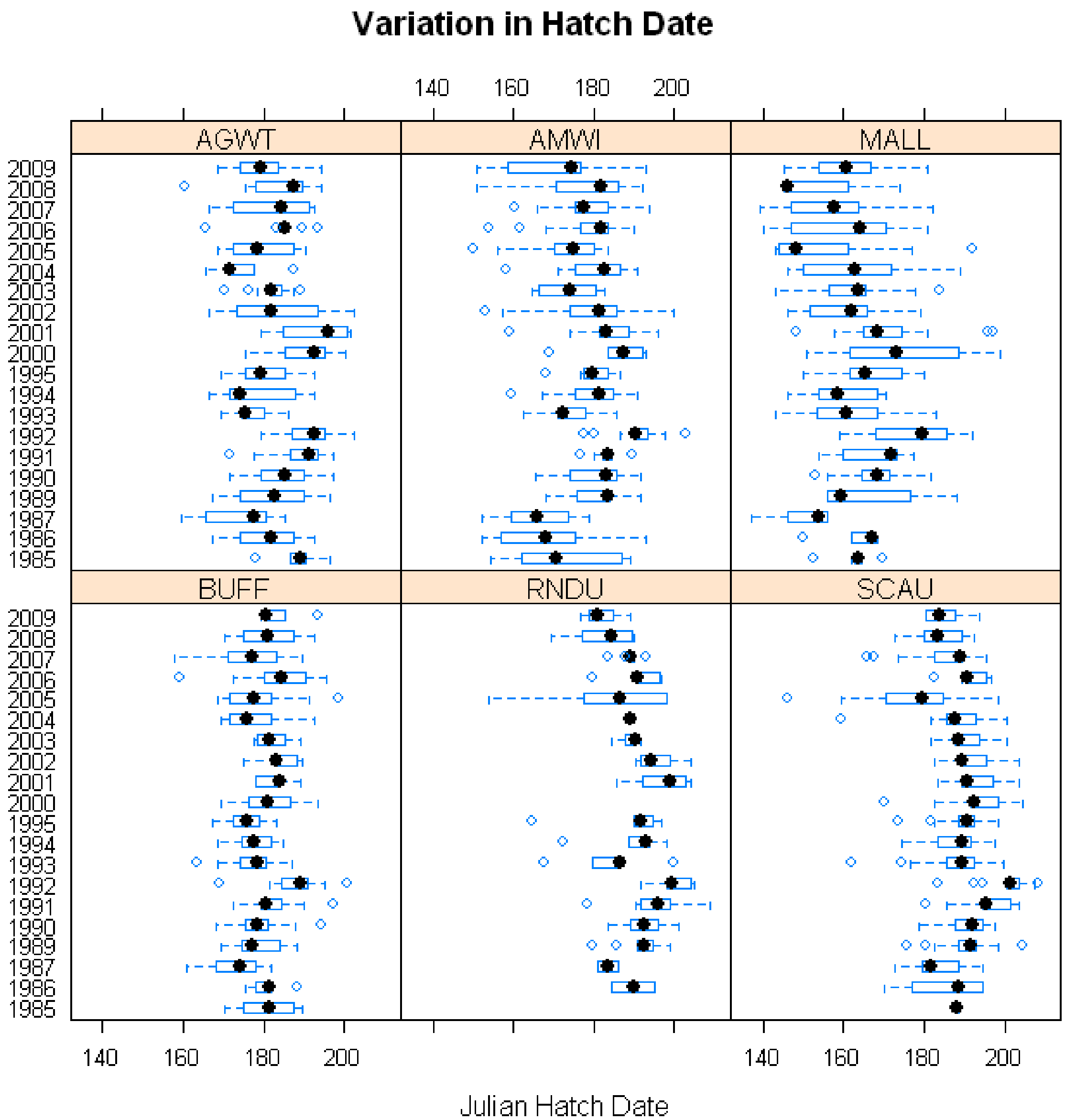

Figure 4. Brood age class distributions during survey, by species (panel) and year (column within plot). Age class distribution varies widely across years and species.

a. Dabblers. Mallards have more evenly distributed age class distributions than other dabblers.

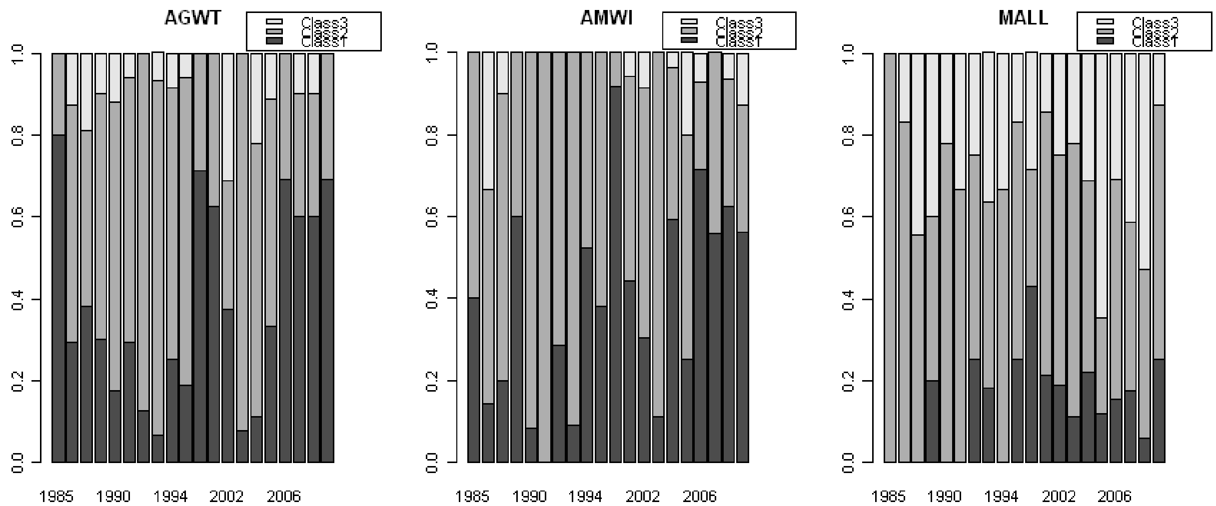

Figure 4b. Divers. Ring-necked Duck and Scaup are predominantly observed as age class I young.

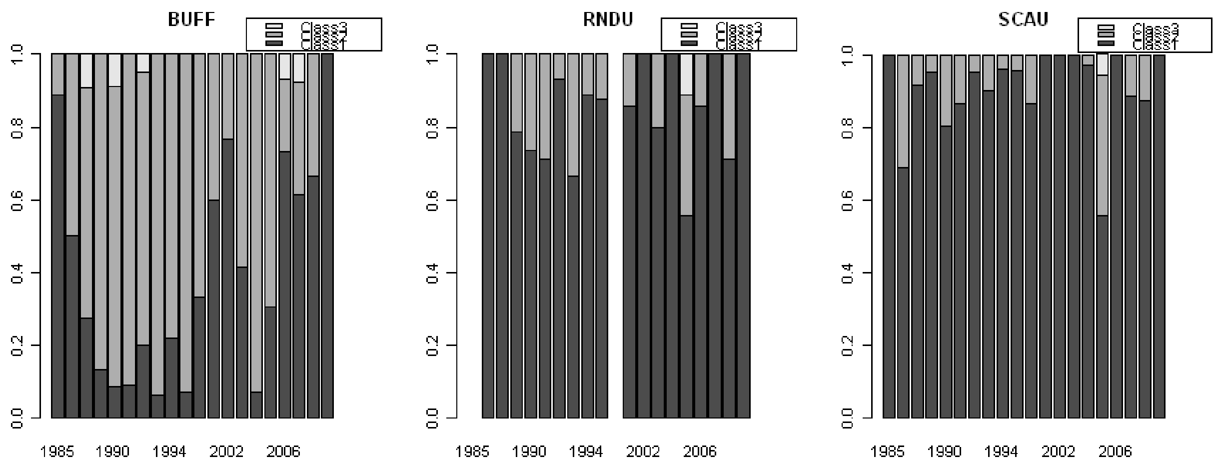

Figure 5. Scatterplots of annual mean hatch date for each pair of regularly observed species. The mean hatch dates between many species are relatively highly correlated (with the notable exception of BUFF). Note the change in scale among the axes.

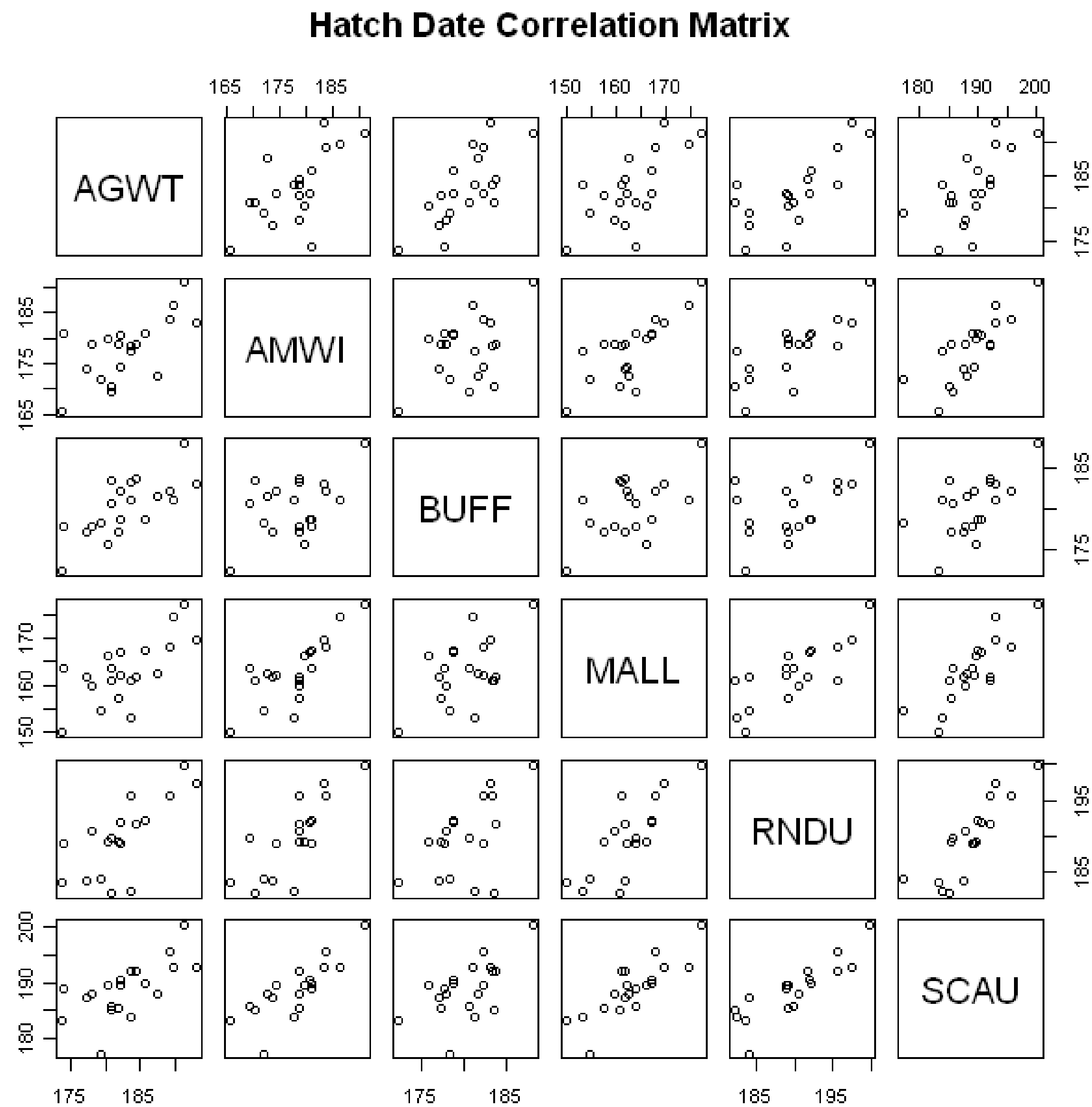

Figure 6. Tetlin NWR with 11 clusters and productivity strata labeled (red = low, orange = medium, green = high). Strata were defined geographically.

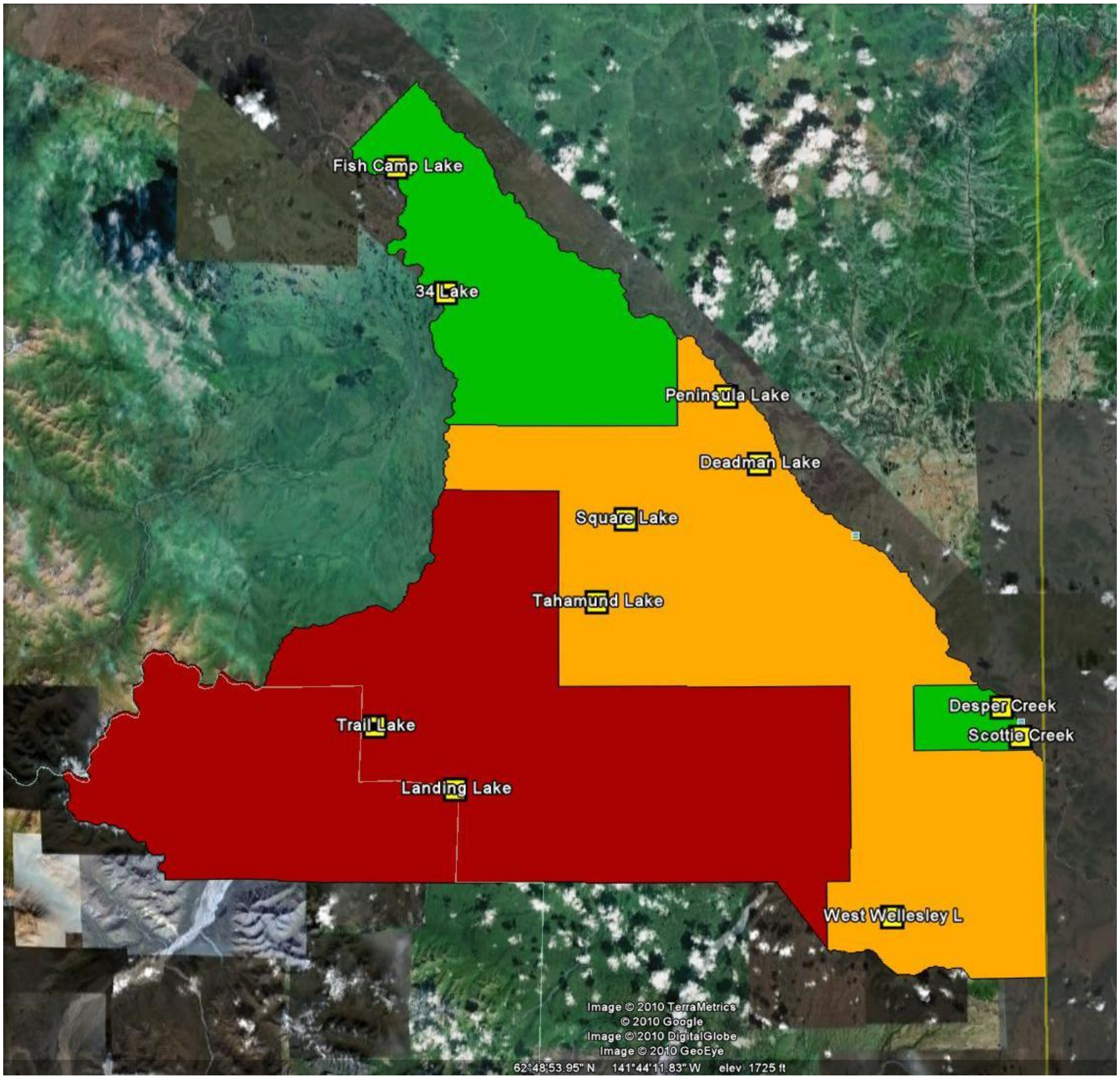

Figure 7. Number of AGWT young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in the low and medium strata clusters.

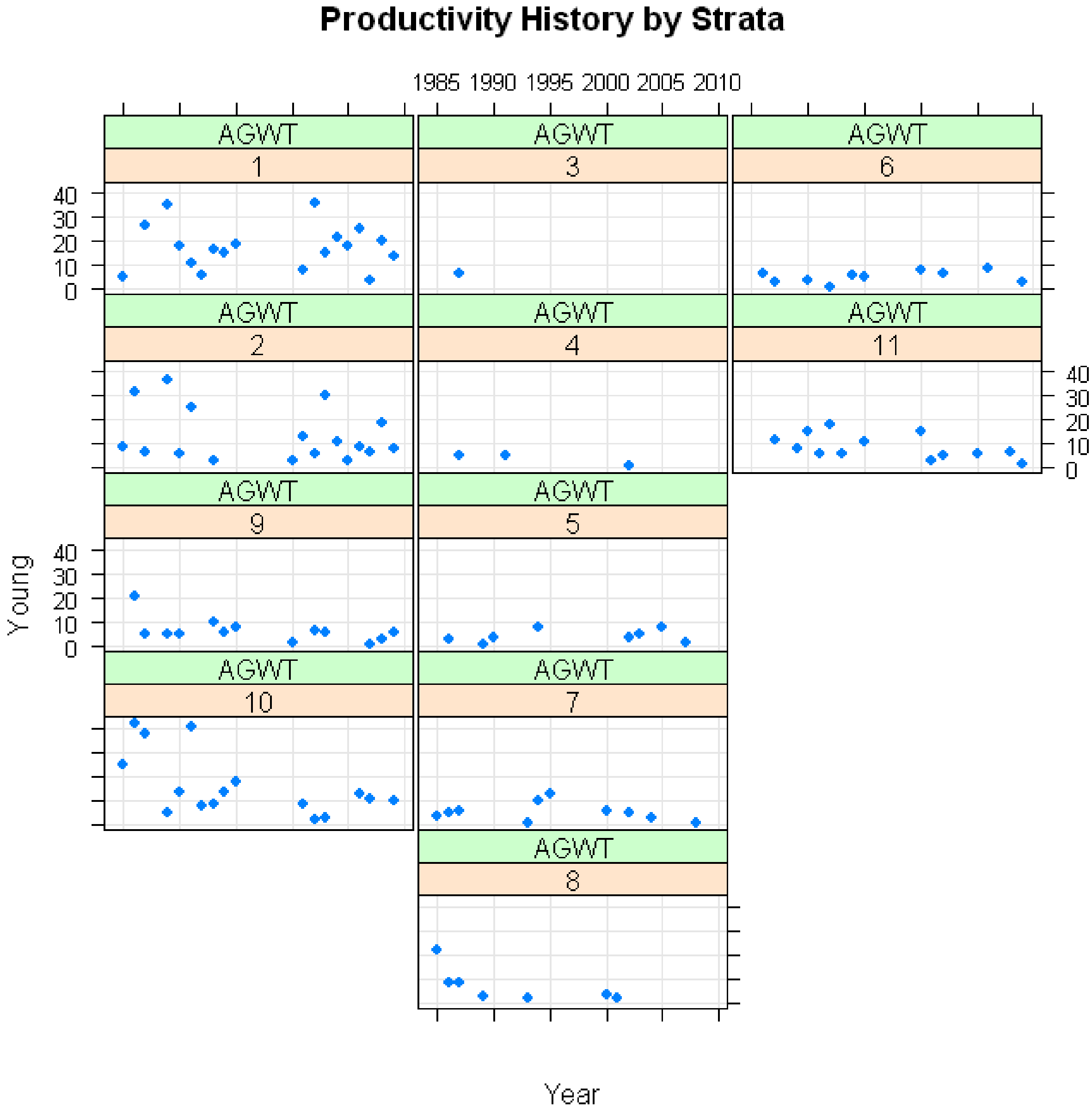

Figure 8. Number of AMWI young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in the low and medium strata clusters.

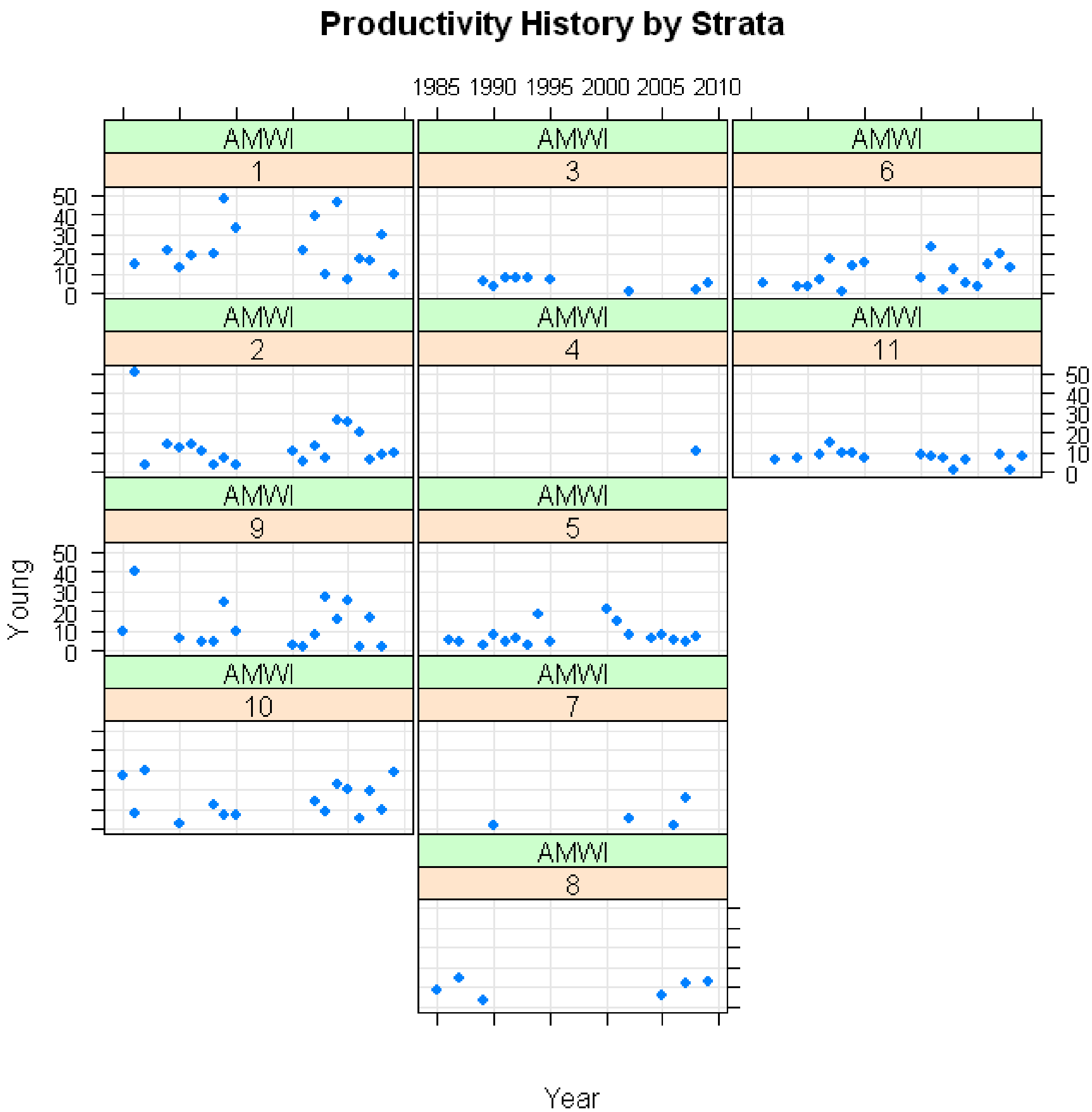

Figure 9. Number of MALL young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in any of the strata clusters.

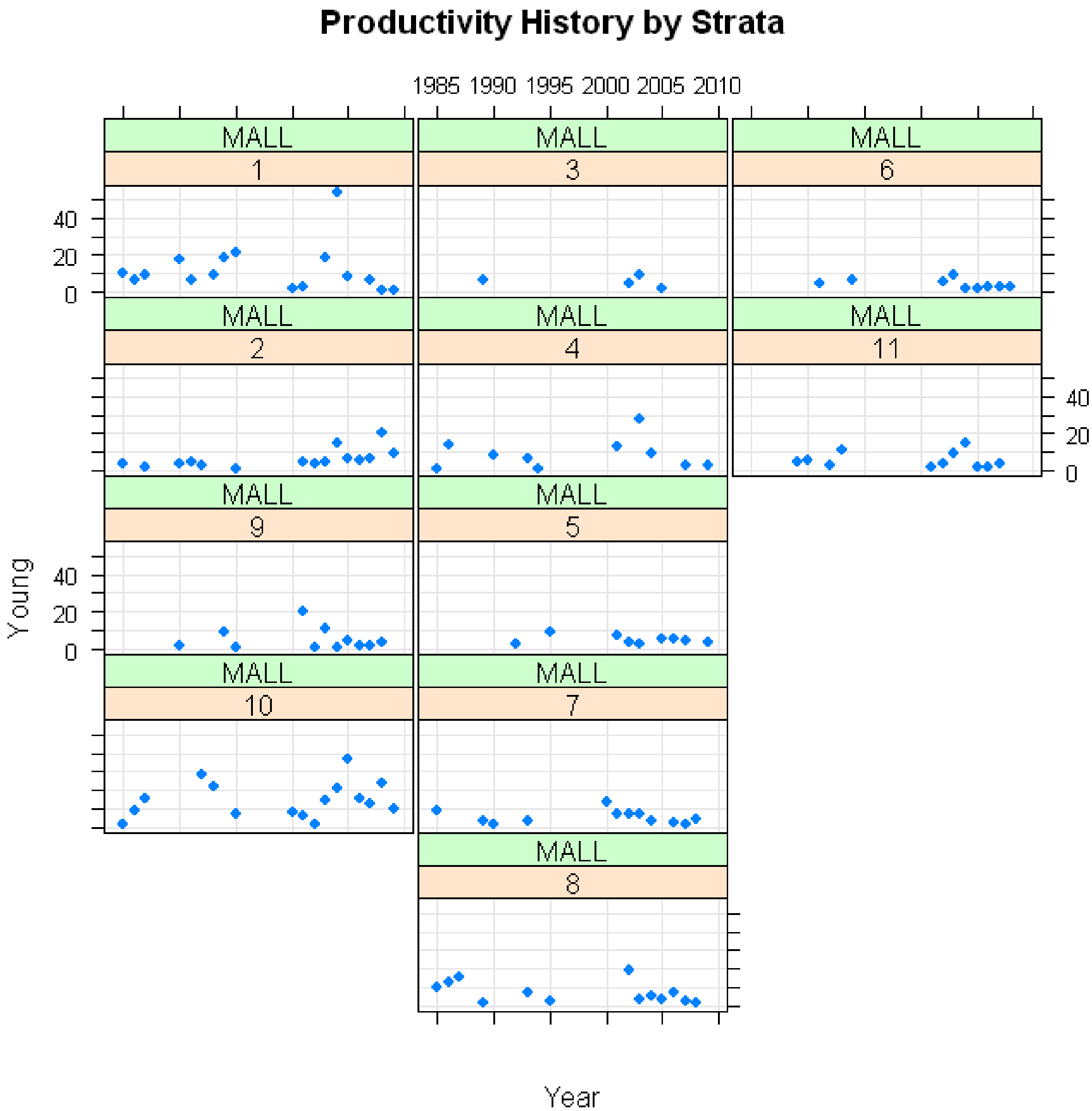

Figure 10. Number of BUFF young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in the low and medium strata clusters.

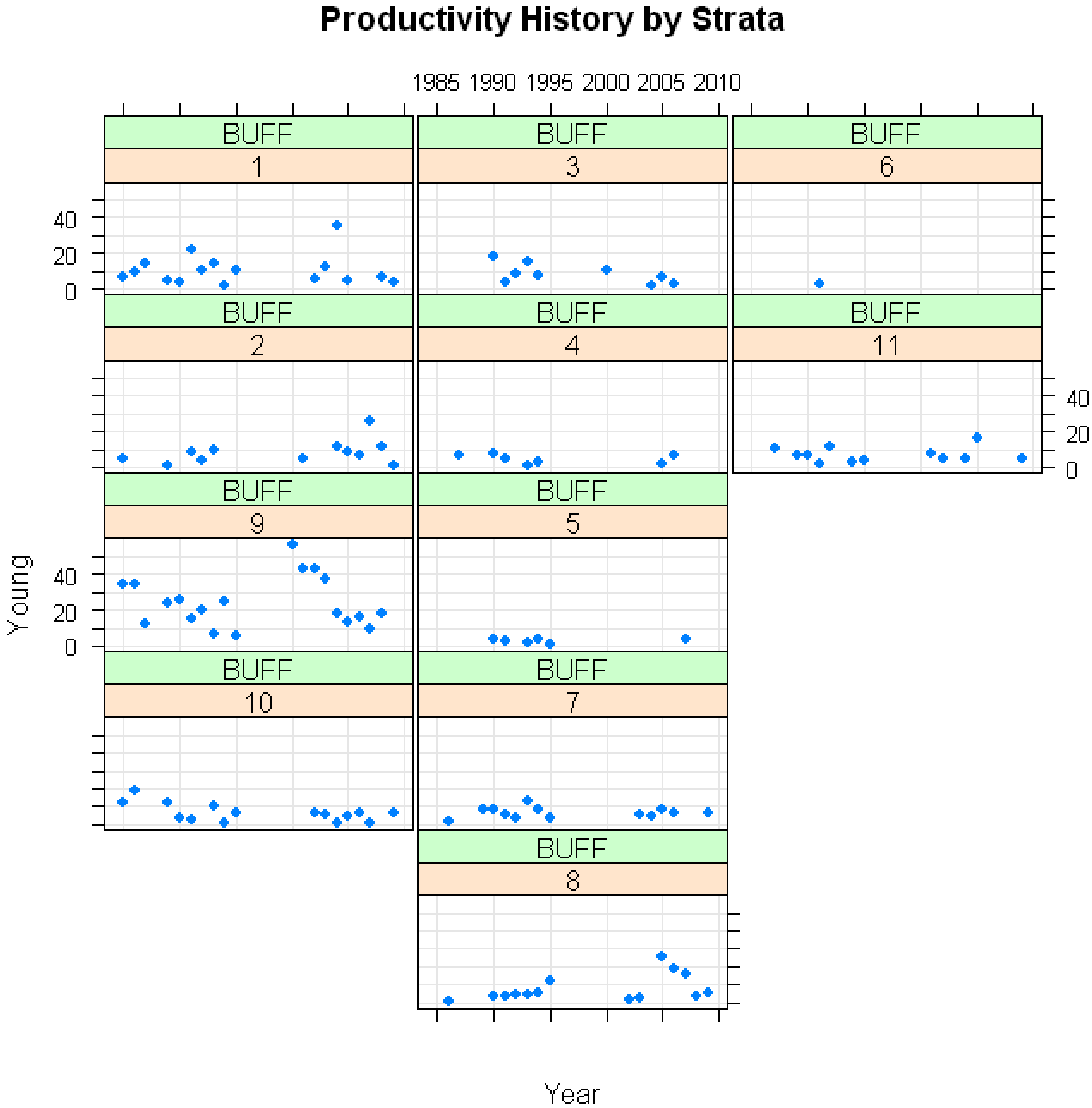

Figure 11. Number of RNDU young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in any of strata.

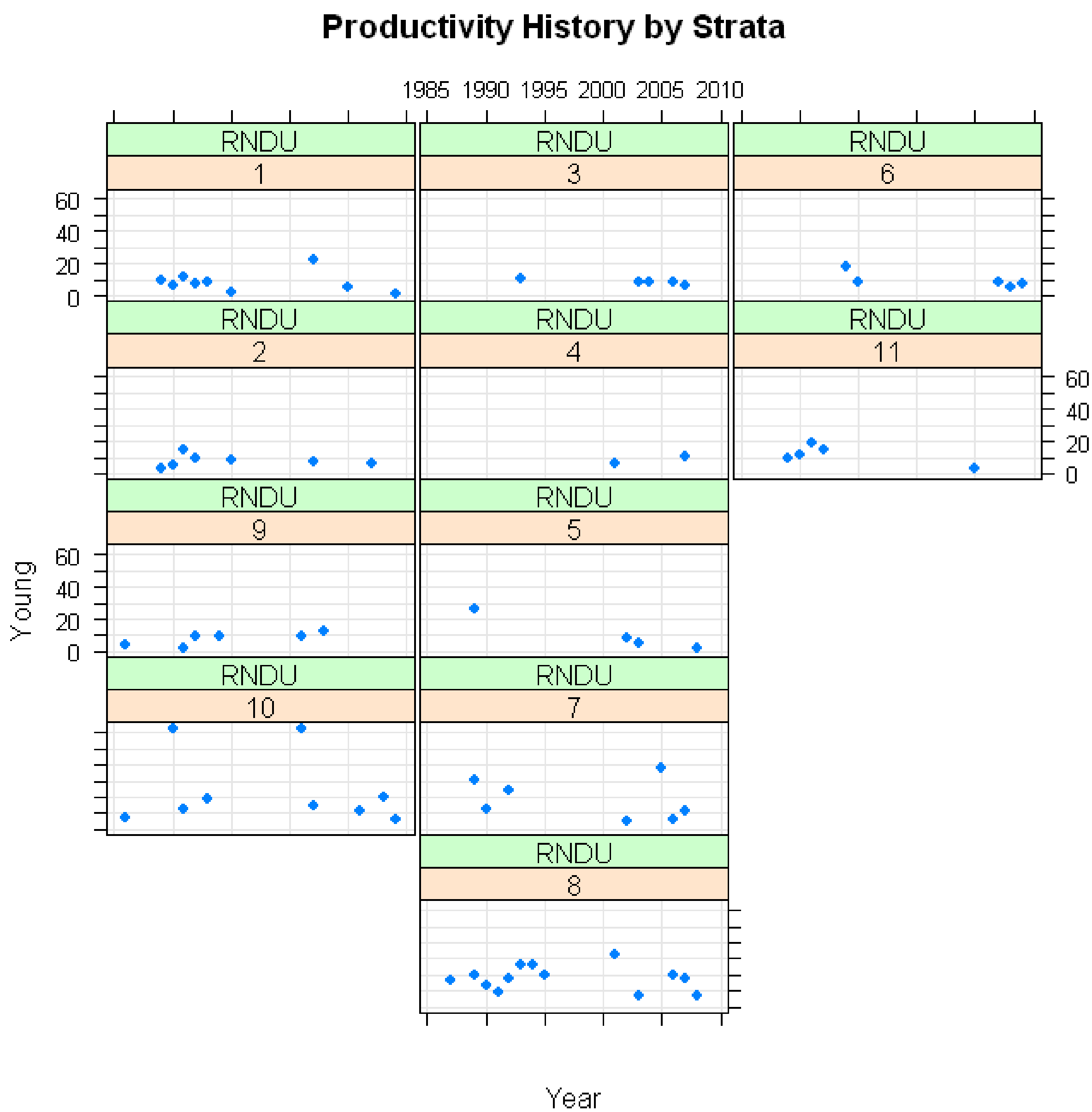

Figure 12. Number of SCAU young observed on each cluster (panel) each year (horizontal axis). The first column is the high stratum, the second is the medium stratum, the third is the low stratum. Production levels are indistinguishable in the low and medium strata clusters.

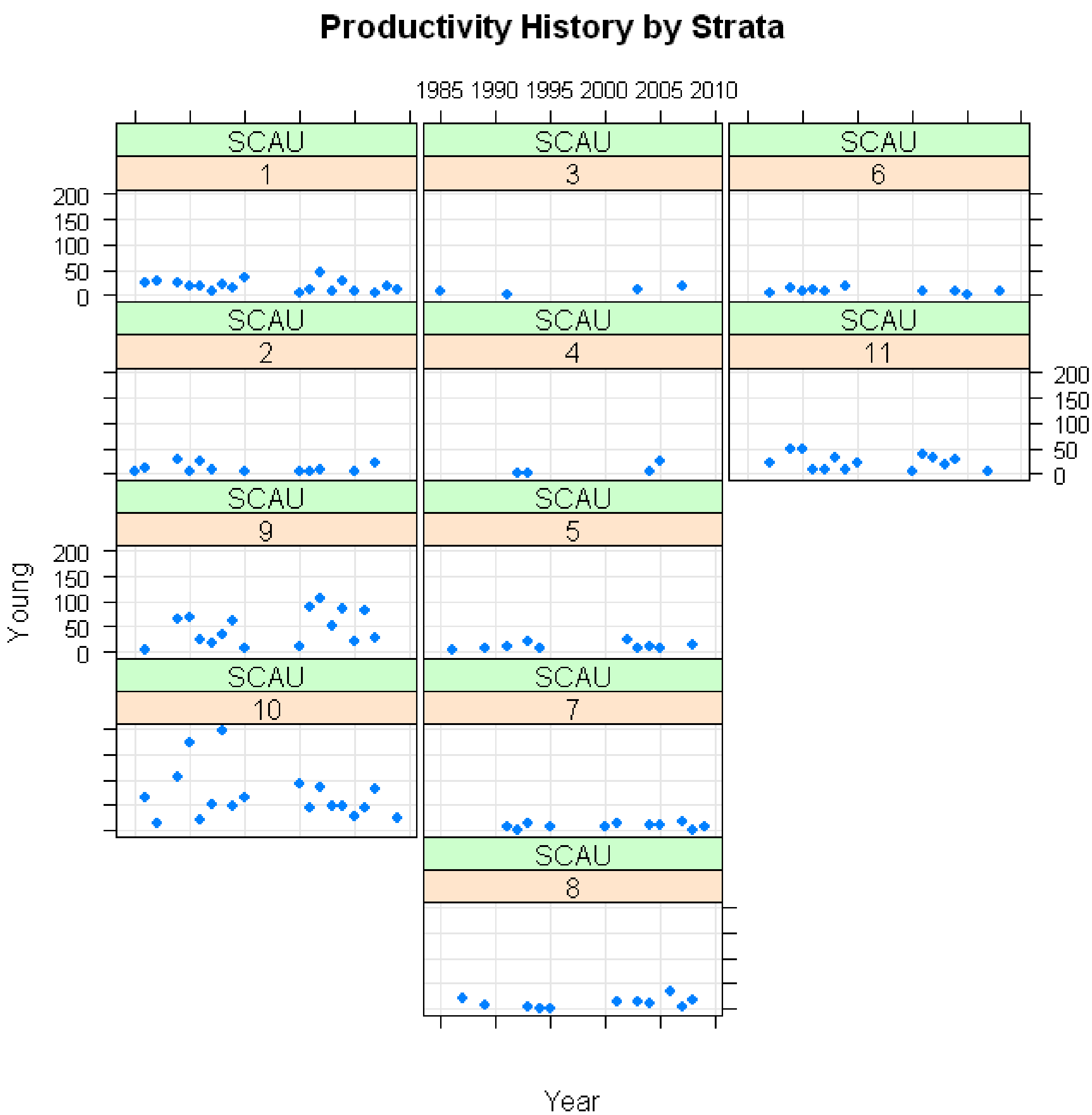

Figure 13. Number of young observed of each species (panel) on each cluster (dot) each year (horizontal axis), by strata (dot color). Low and medium strata are indistinguishable.

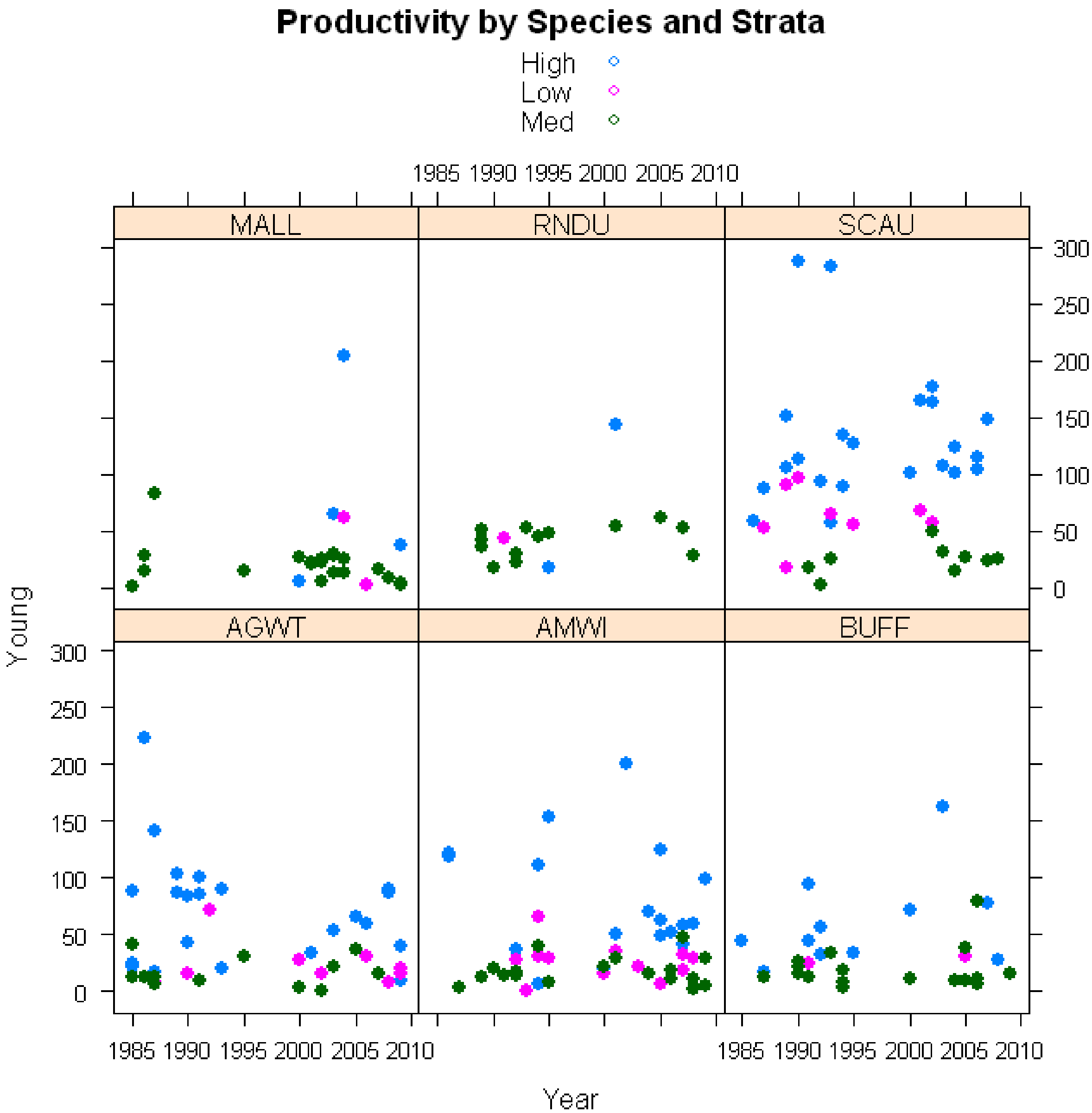

Figure 14. Average brood size per age class (I,II,III) by species, summarized across all years. Brood size decreases as age class increases.

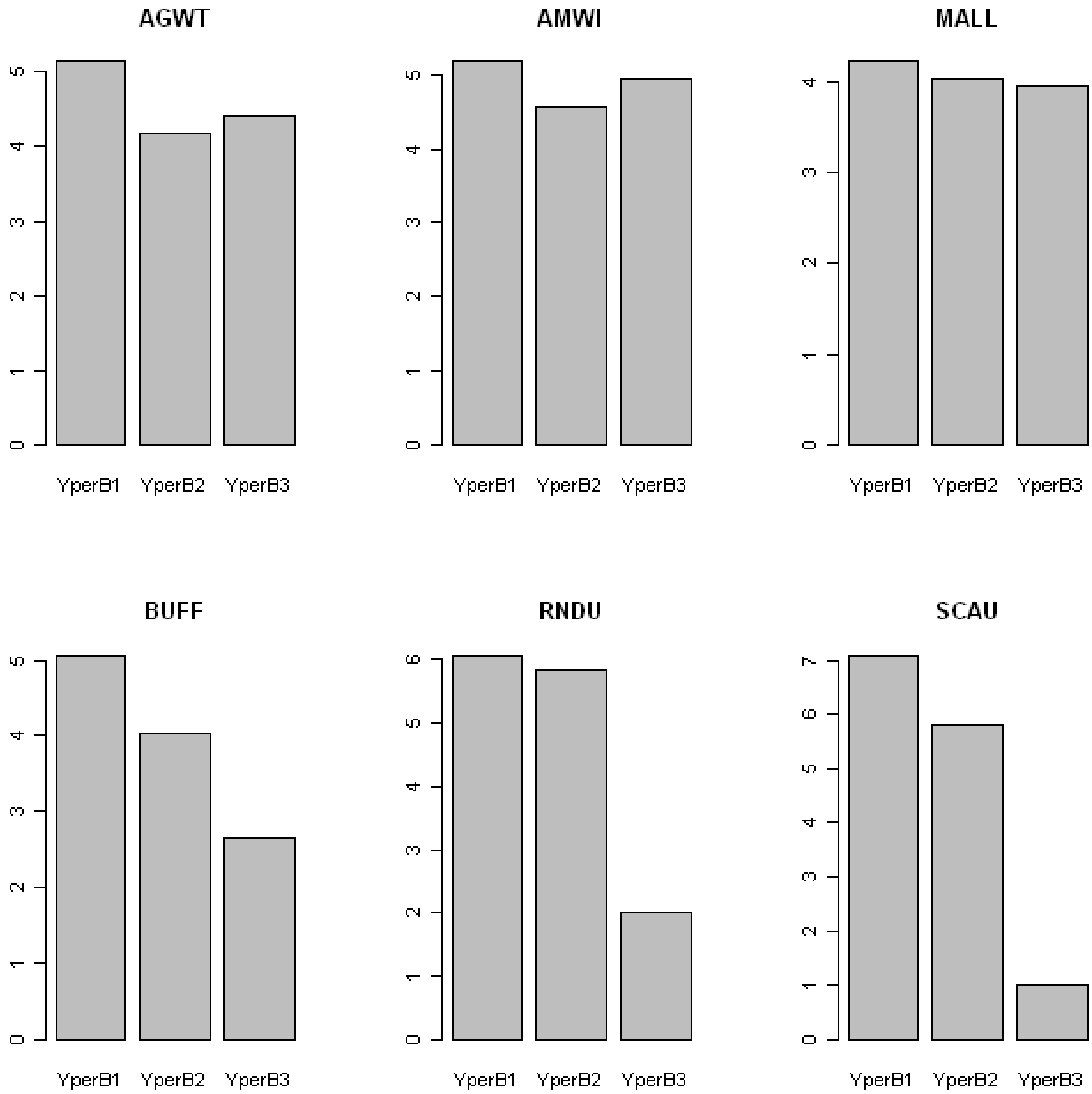

Figure 15. Probability of Young Survival (horizontal axis) vs. probability of Brood Survival (vertical axis) for original brood sizes of 5 to12 young (curves). Brood survival rate was assumed to follow a binomial distribution (constant probability of duckling survival, survival of ducklings within a brood are independent events). Reference line added at a probability of brood survival of 90%. Broods are much more likely than young to survive the full season.

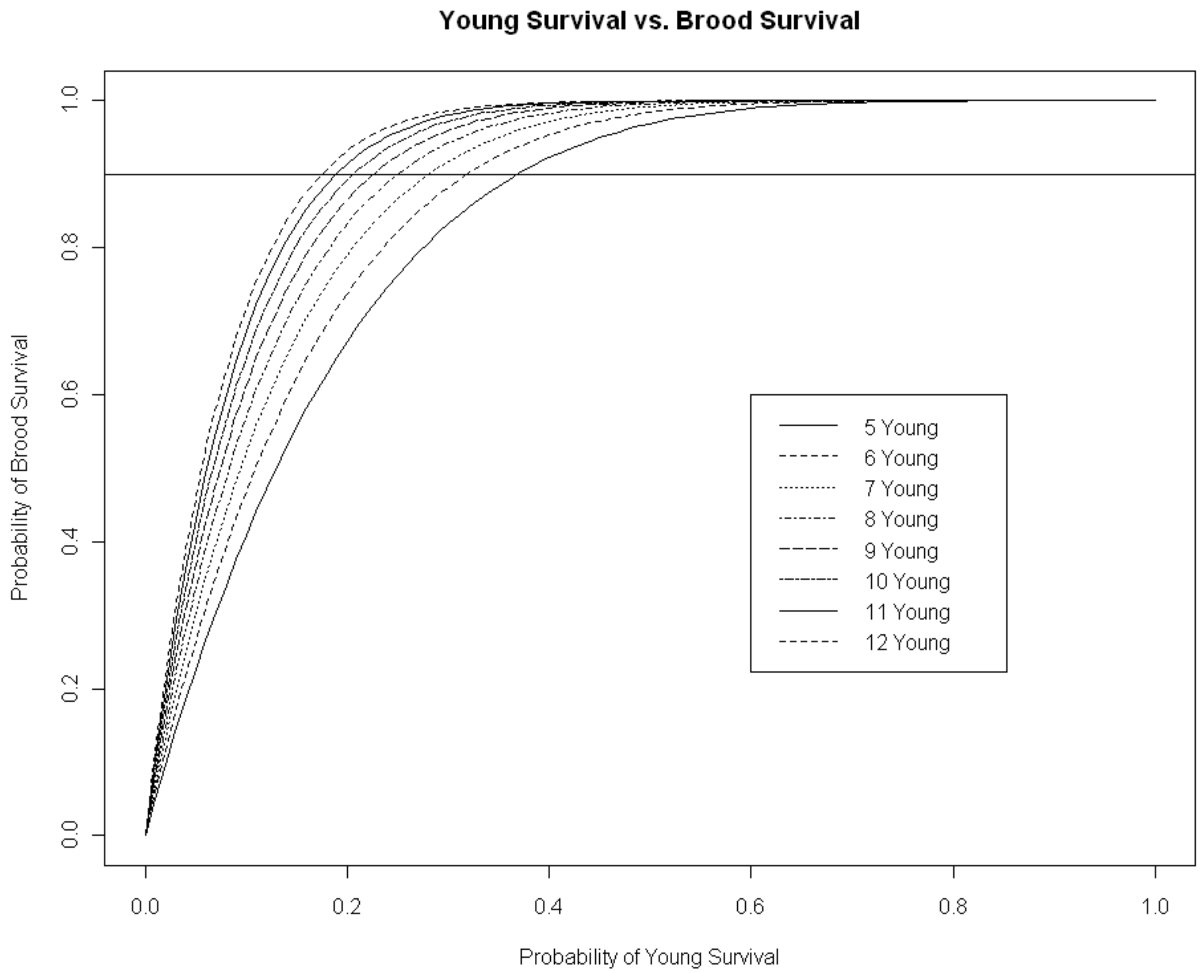

Figure 16. Number of young observed (horizontal axis) vs predicted to survive to fledging (vertical axis) under the 65% total within season mortality model, by species (panel). The least-squares regression line (solid) has been added to the plot for visual reference, as has the 1-to-1 line of equality (dashed). There is a large decrease in the number of young expected to fledge vs those observed for RNDU and SCAU.

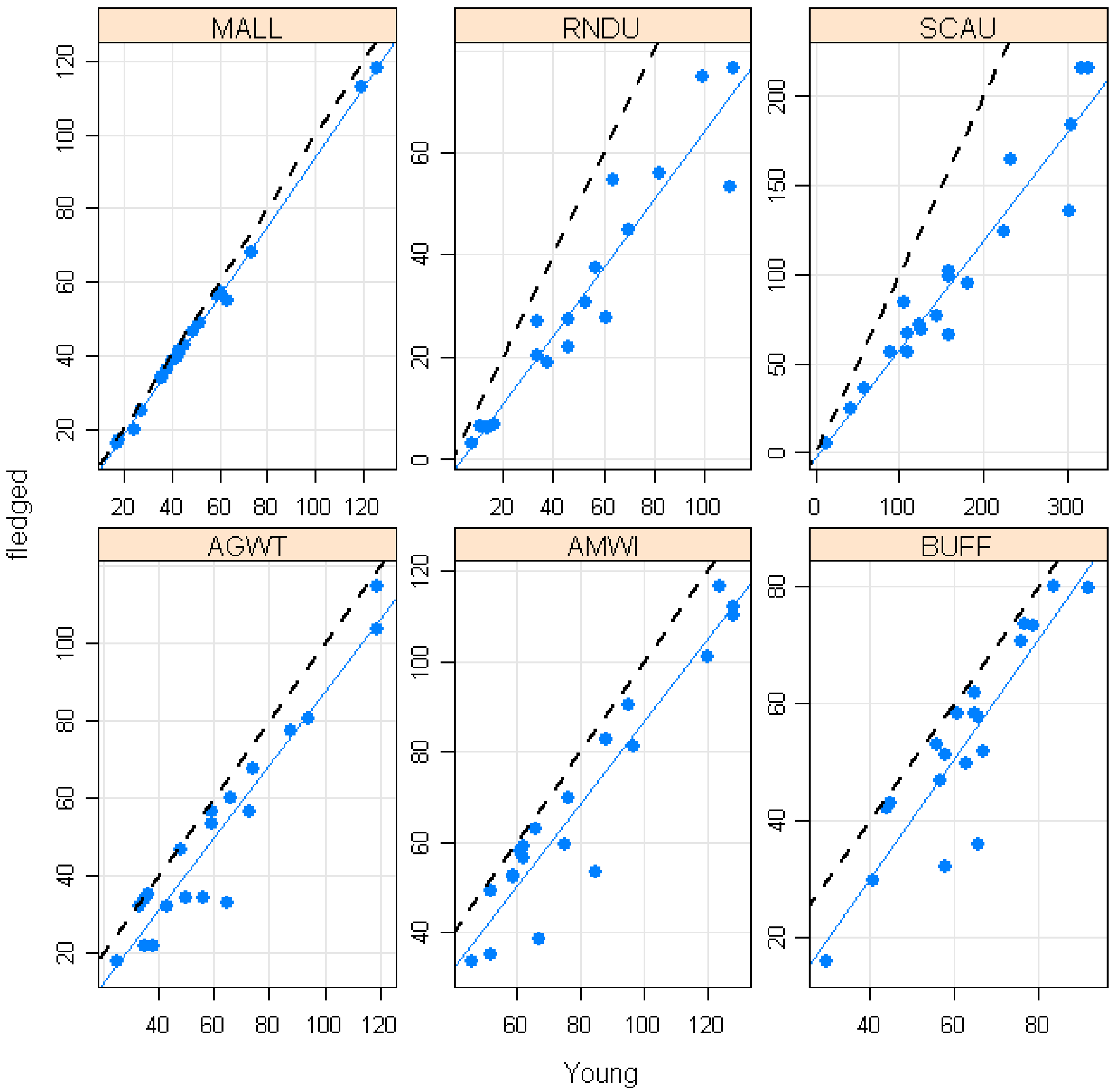

Figure 17. Number of young observed (horizontal axis) vs predicted to survive to fledging (vertical axis) under the 85% total within season mortality model, by species (panel). The least-squares regression line (solid) has been added to the plot for visual reference, as has the 1-to-1 line of equality (dashed). There is a large decrease in the number of young expected to fledge vs those observed for RNDU and SCAU.

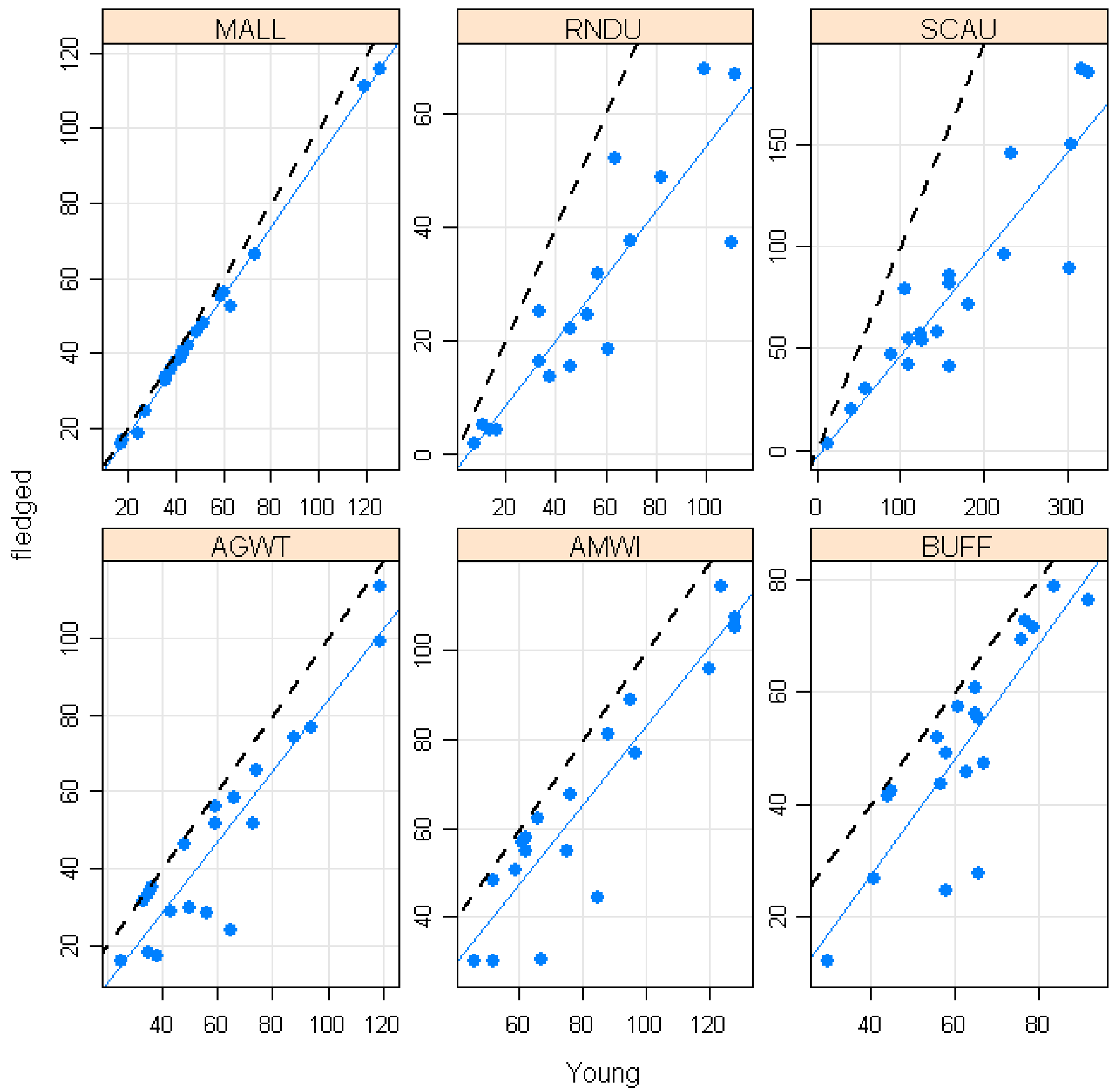

Figure 18. Number of young observed (horizontal axis) vs predicted to survive to fledging (vertical axis) under the 95% total within season mortality model, by species (panel). The least-squares regression line (solid) has been added to the plot for visual reference, as has the 1-to-1 line of equality (dashed). There is a large decrease in the number of young expected to fledge vs those observed for RNDU and SCAU.

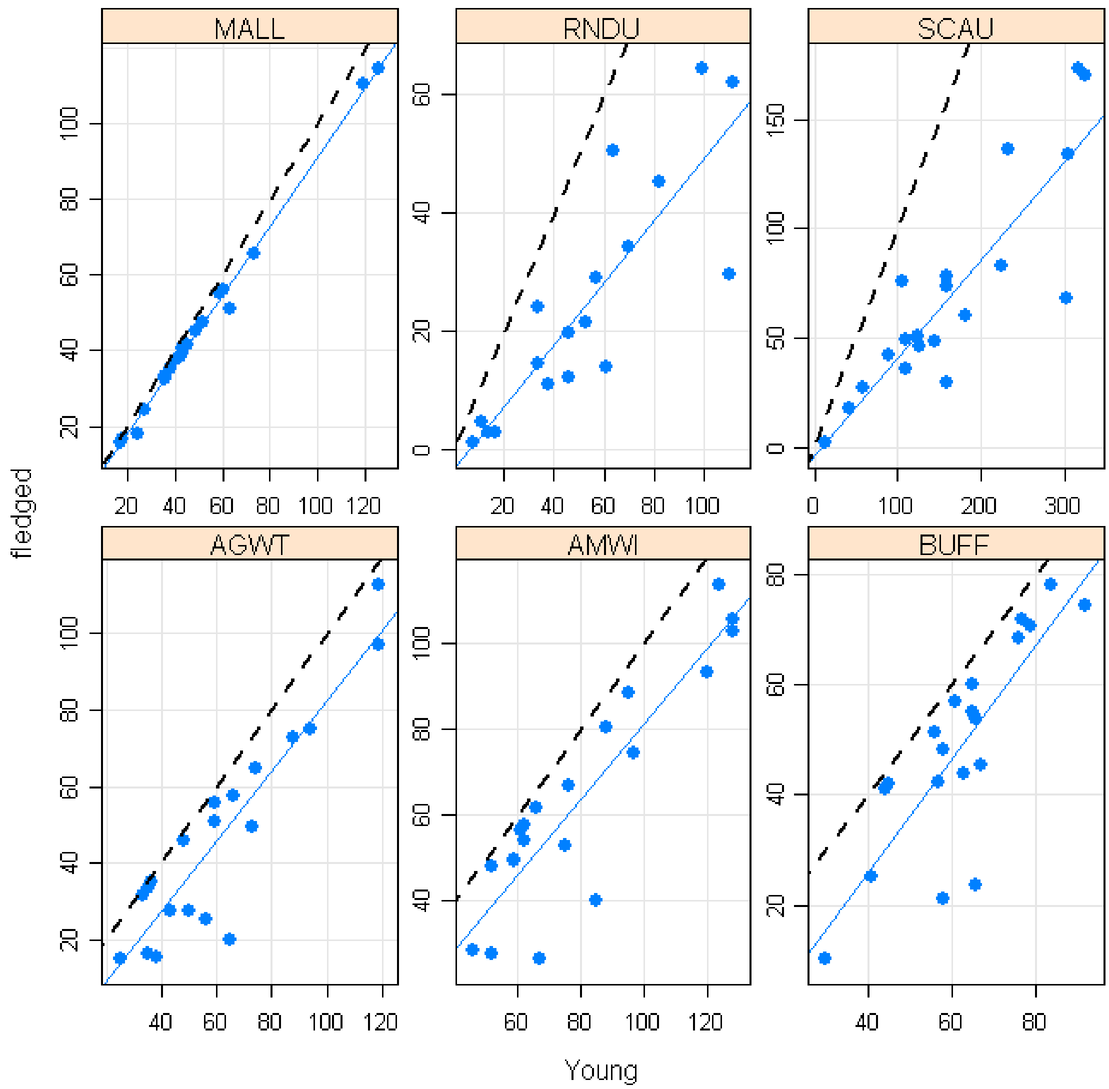

Figure 19. Annual trends in number of observed young (circles, solid line) and predicted fledged young (crosses, dashed line) using the 65% total within-season mortality model. The observed young trend and the predicted young trend differ for AMWI.

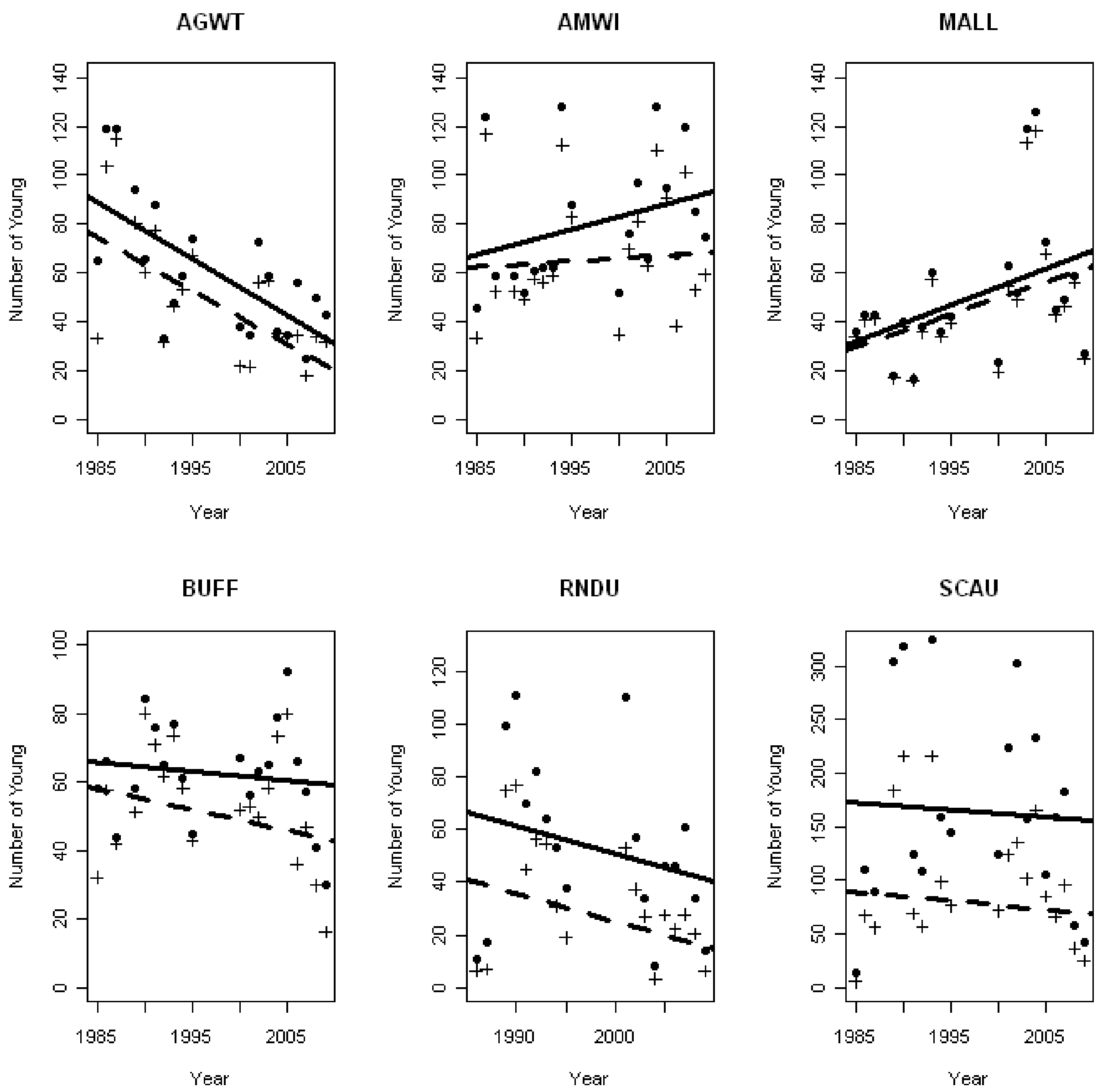

Figure 20. Annual trends in number of observed young (circles, solid line) and predicted fledged young (crosses, dashed line) using the 85% total within-season mortality model. The observed young trend and the predicted young trend are different for AMWI.

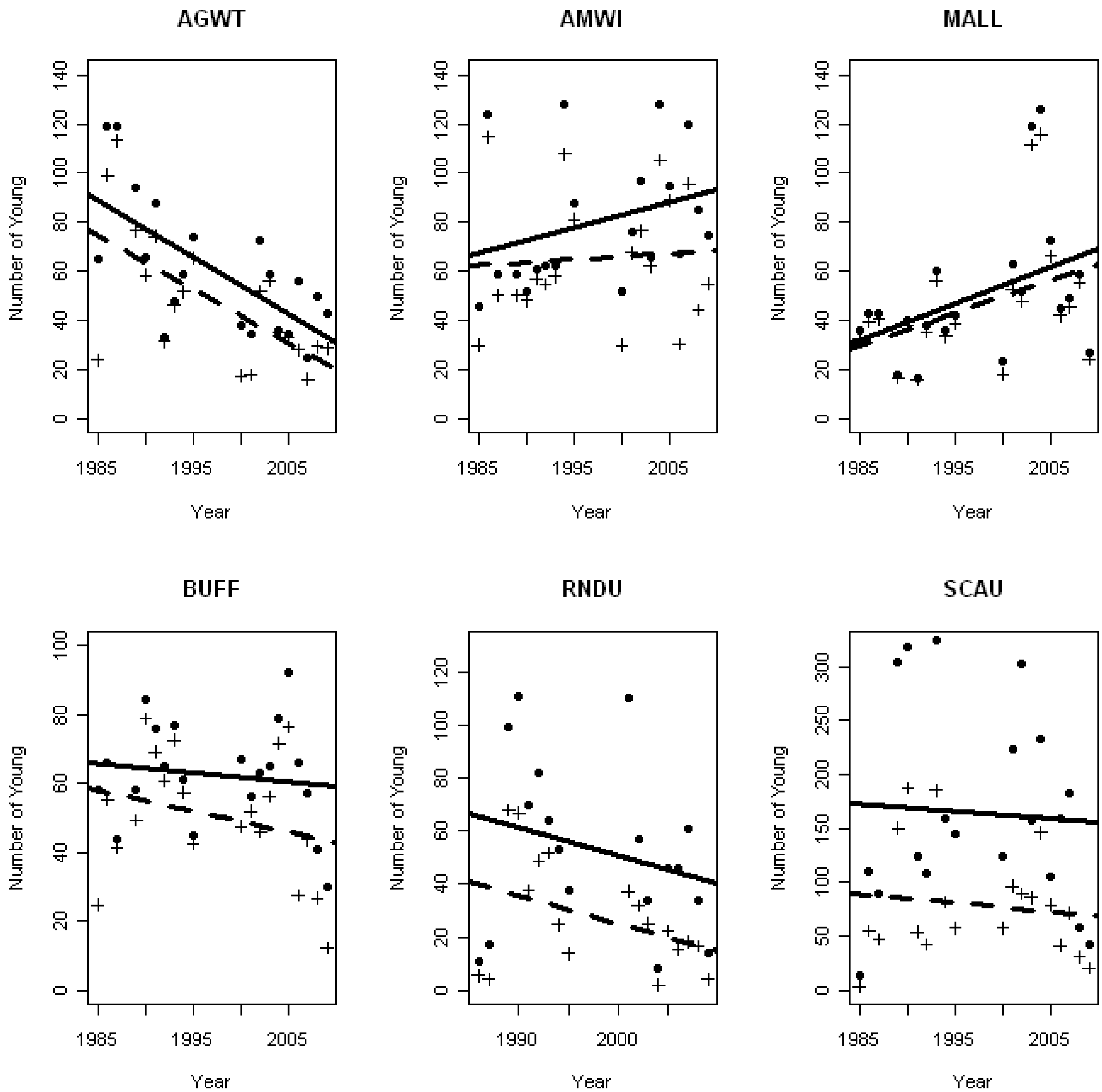

Figure 21. Annual trends in number of observed young (circles, solid line) and predicted fledged young (crosses, dashed line) using the 95% total within-season mortality model. The observed young trend and the predicted young trend are different for AMWI.

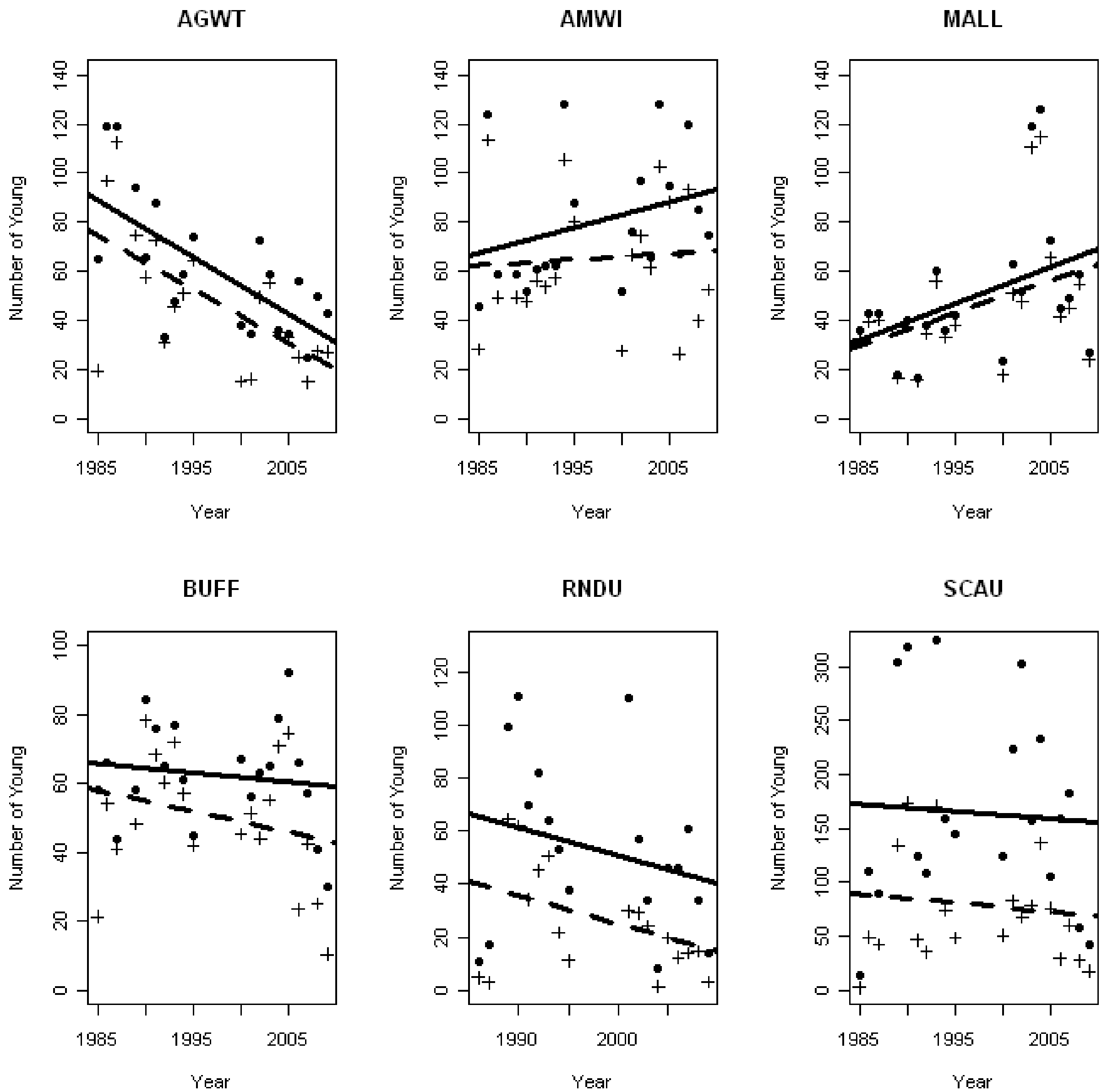

Figure 22. Number of clusters (horizontal axis) required to yield a desired confidence interval half-width (vertical axis) for the mean number of broods per cluster. A dashed line has been added at a confidence interval half-width of 0.75. See Table 1 for observed mean number of broods per cluster for each species.
a. Dabblers

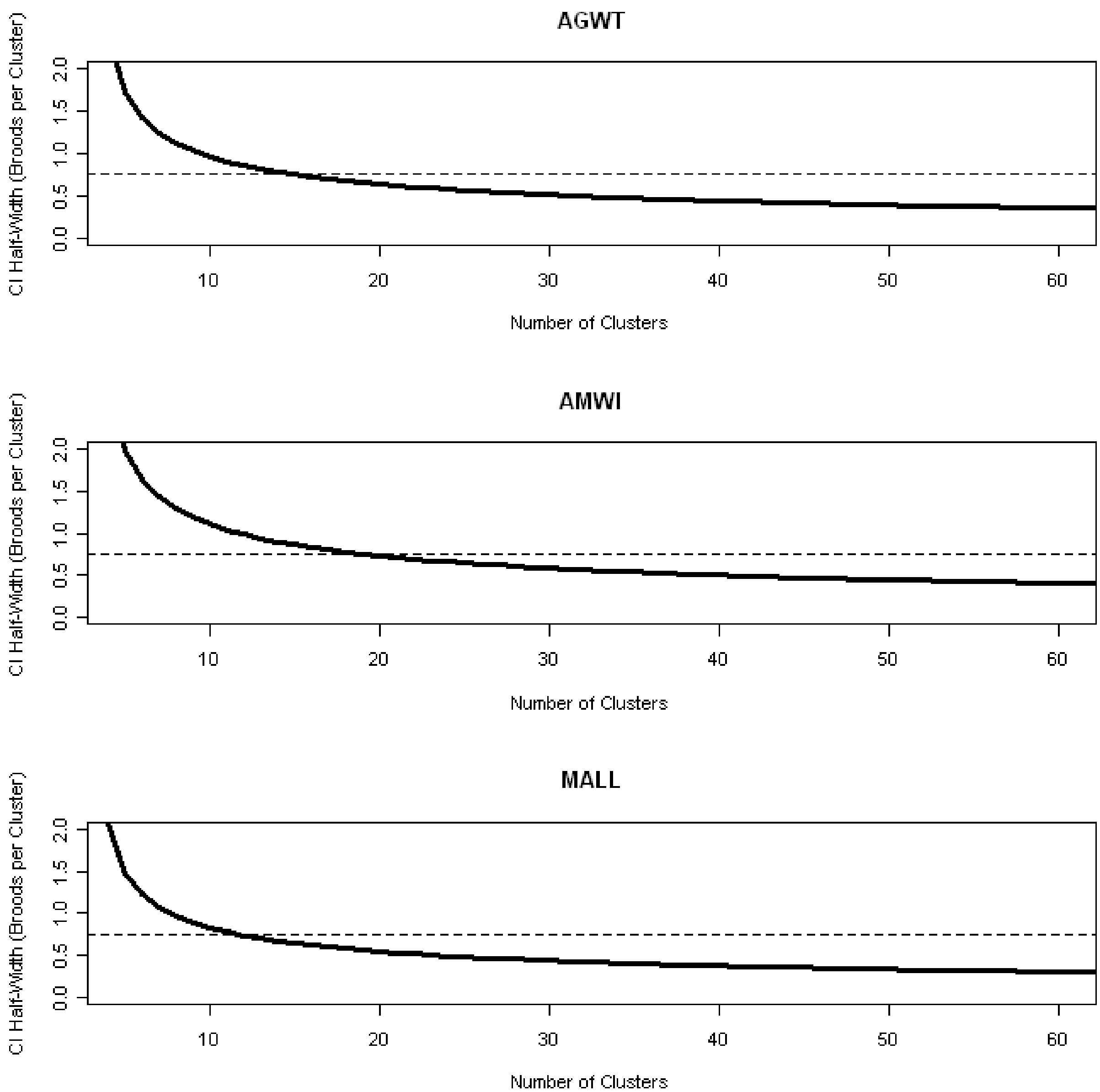

Figure 22b. Divers

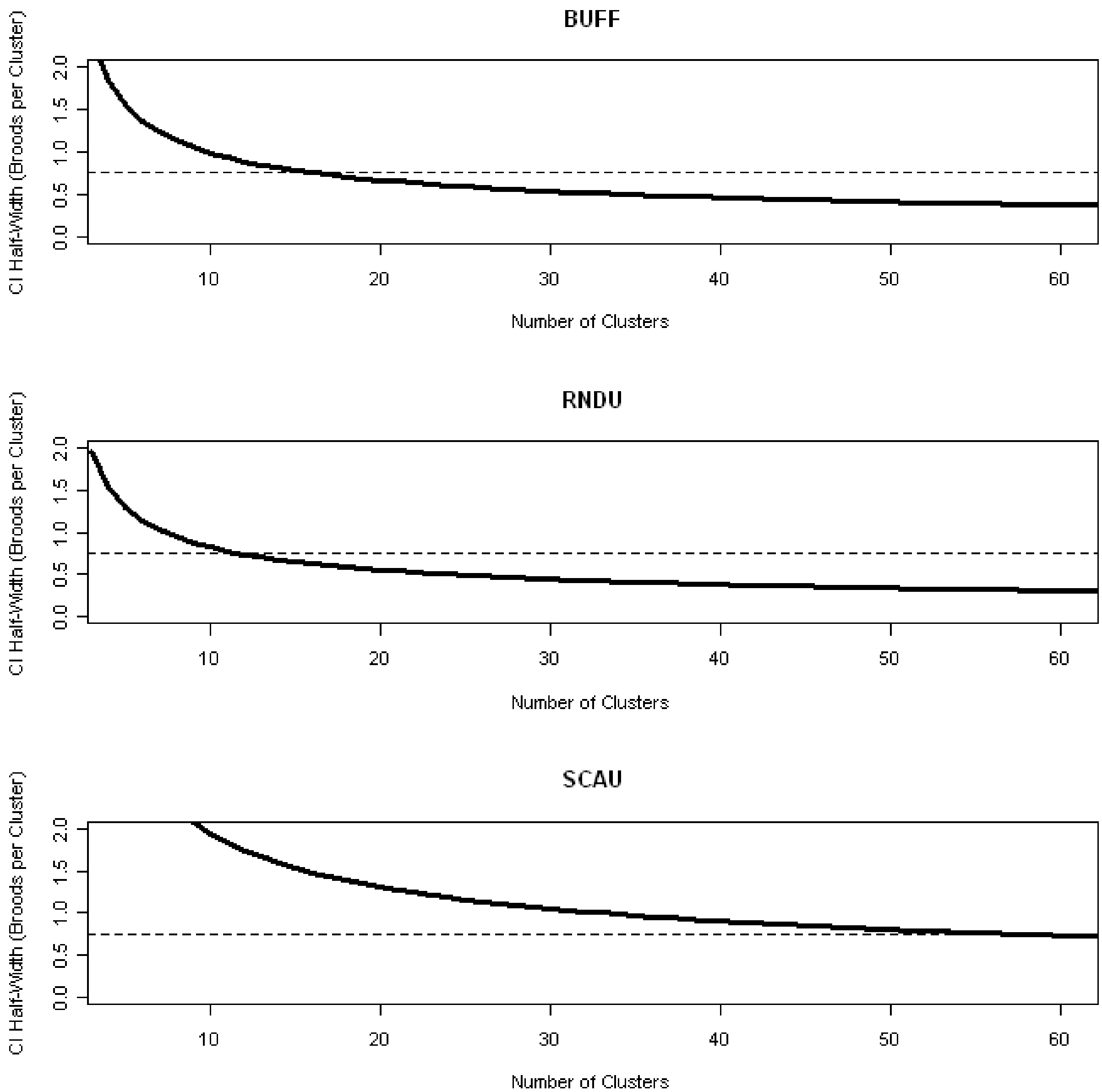

Figure 23. Number of clusters (horizontal axis) required to yield a desired confidence interval half-width (vertical axis) for the mean number of broods per water acre. A dashed line has been added at a confidence interval half-width of 0.0025. See Table 1 for observed mean number of broods per water acre for each species.

a. Dabblers

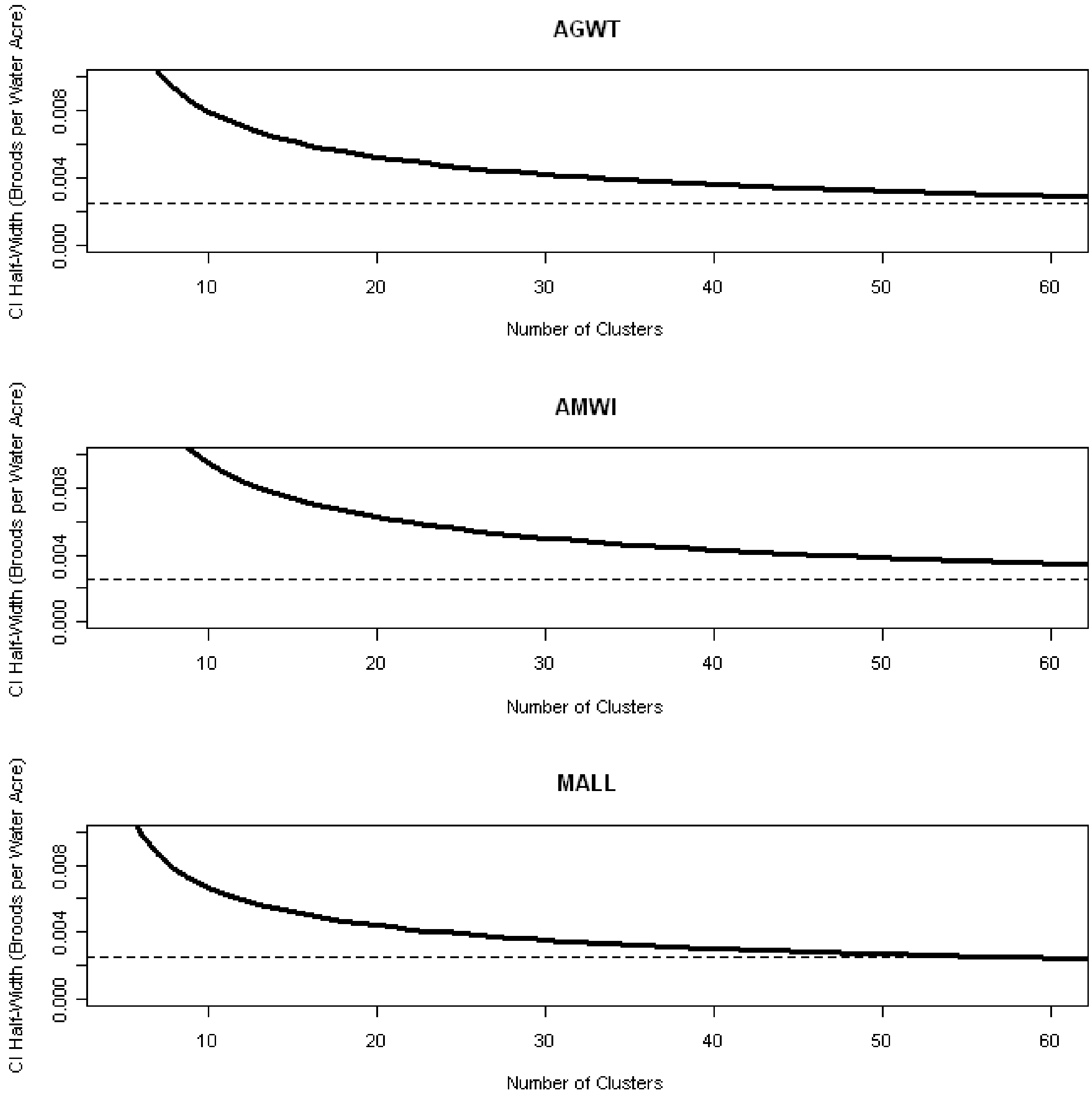

Figure 23b. Divers

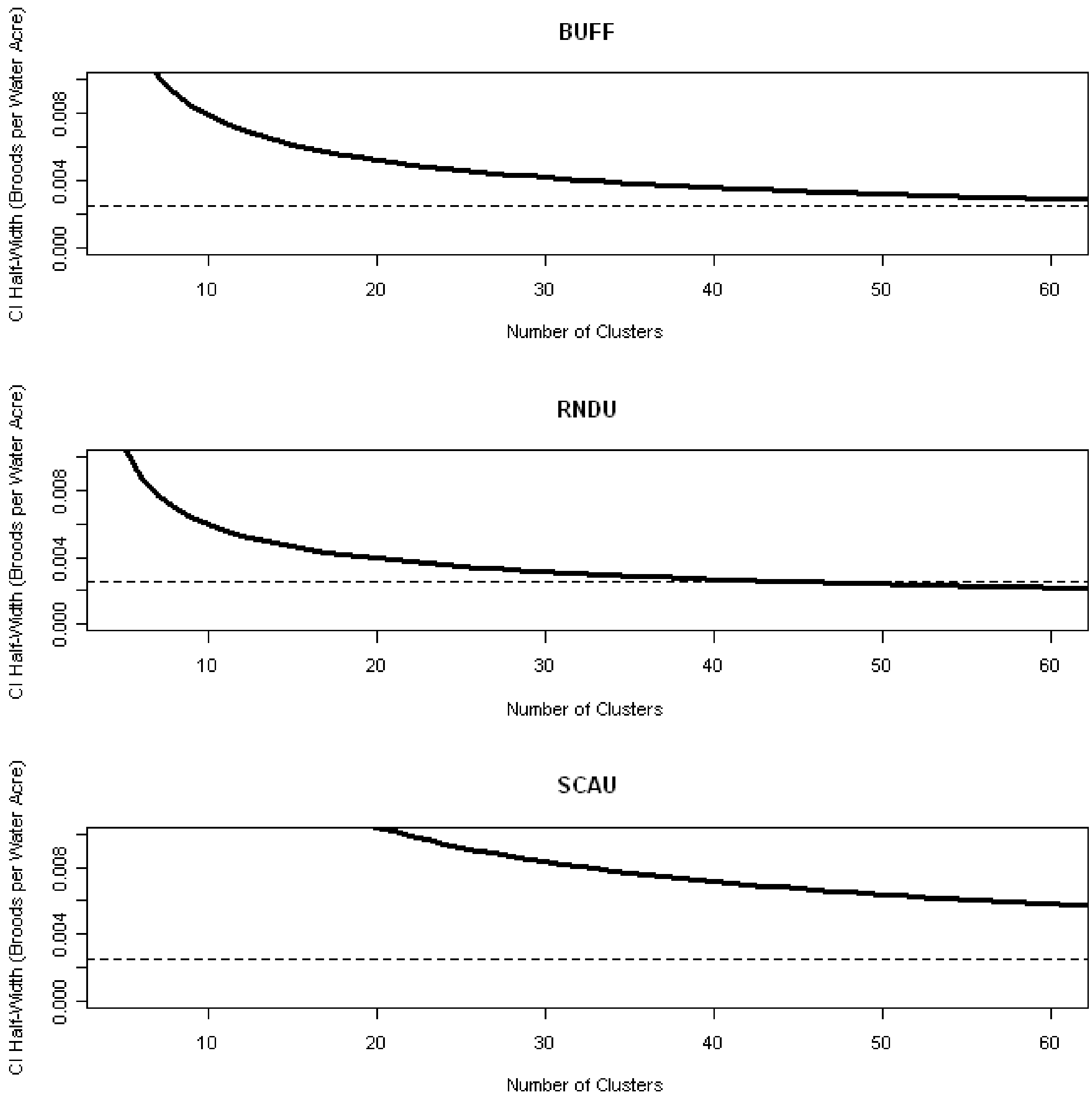

Figure 24. Number of clusters (horizontal axis) required to yield a desired confidence interval half-width (vertical axis) for the mean number of broods per water body. A dashed line has been added at a confidence interval half-width of 0.05. See Table 1 for observed mean number of broods per water body for each species.
a. Dabblers

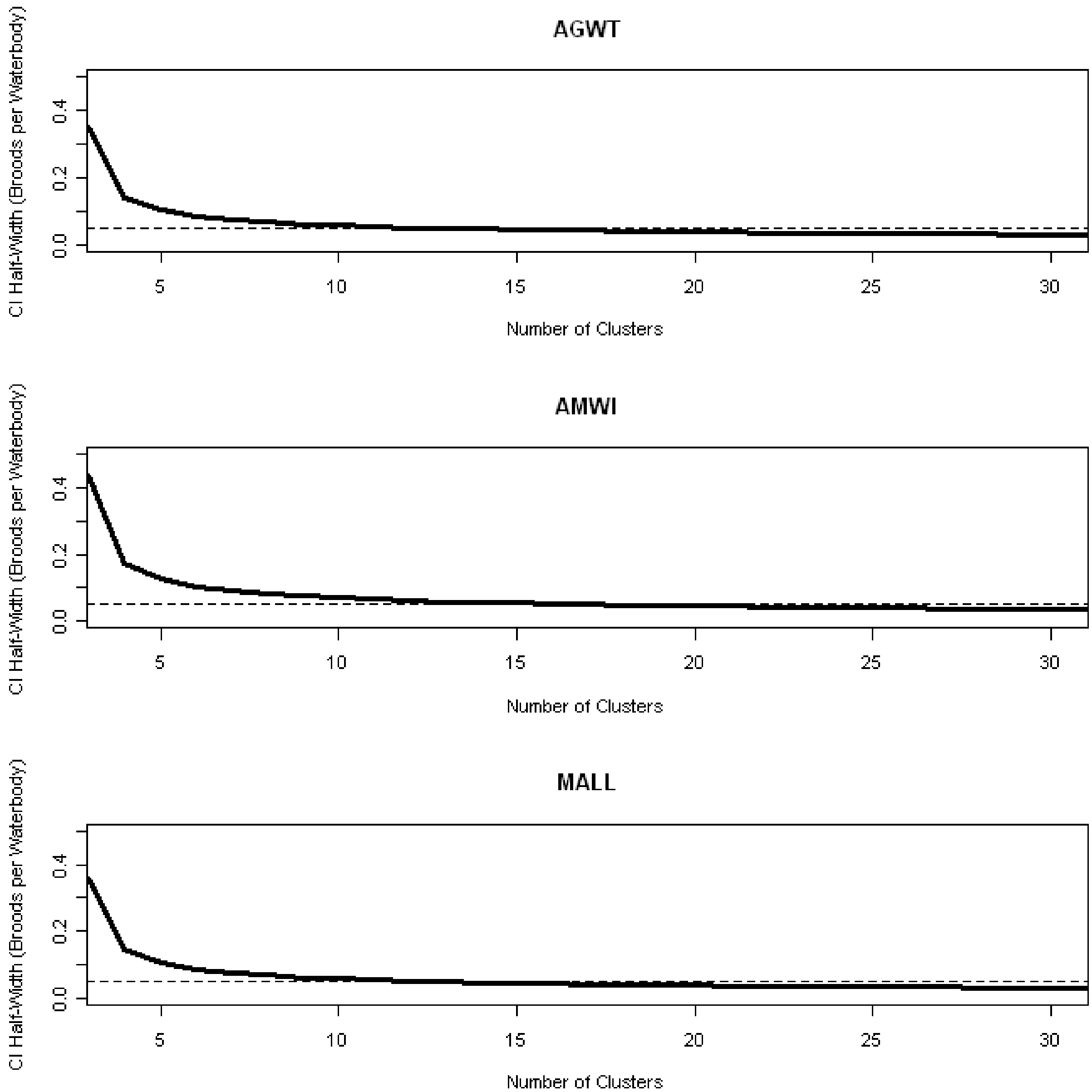

Figure 24b. Divers

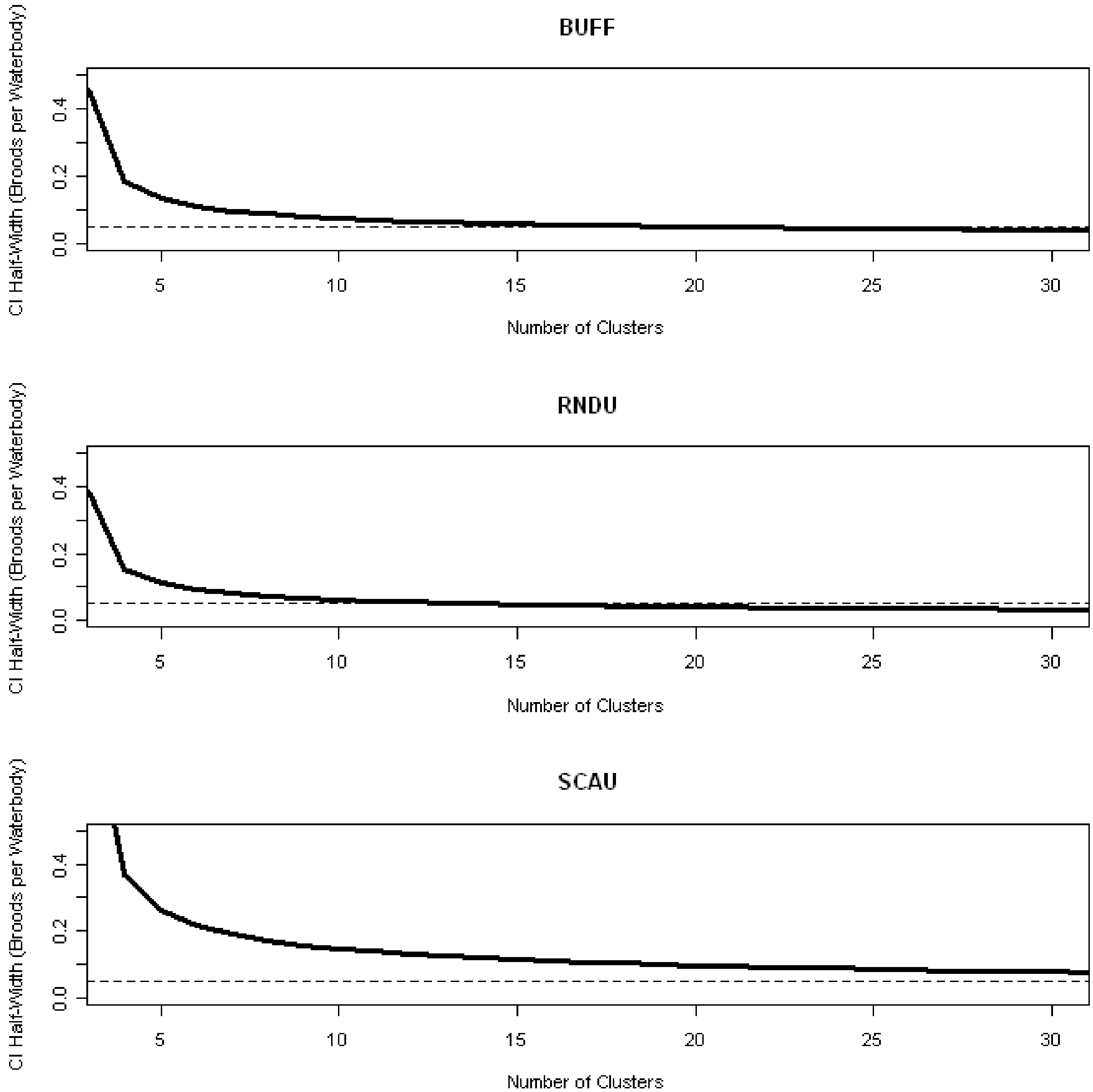

Figure 25. Number of clusters (horizontal axis) required to yield a desired minimum detectable difference between two years in the mean number of broods per cluster. A dashed line has been added at a minimum detectable difference of 0.75. See Table 1 for observed mean number of broods per cluster for each species.
a. Dabblers

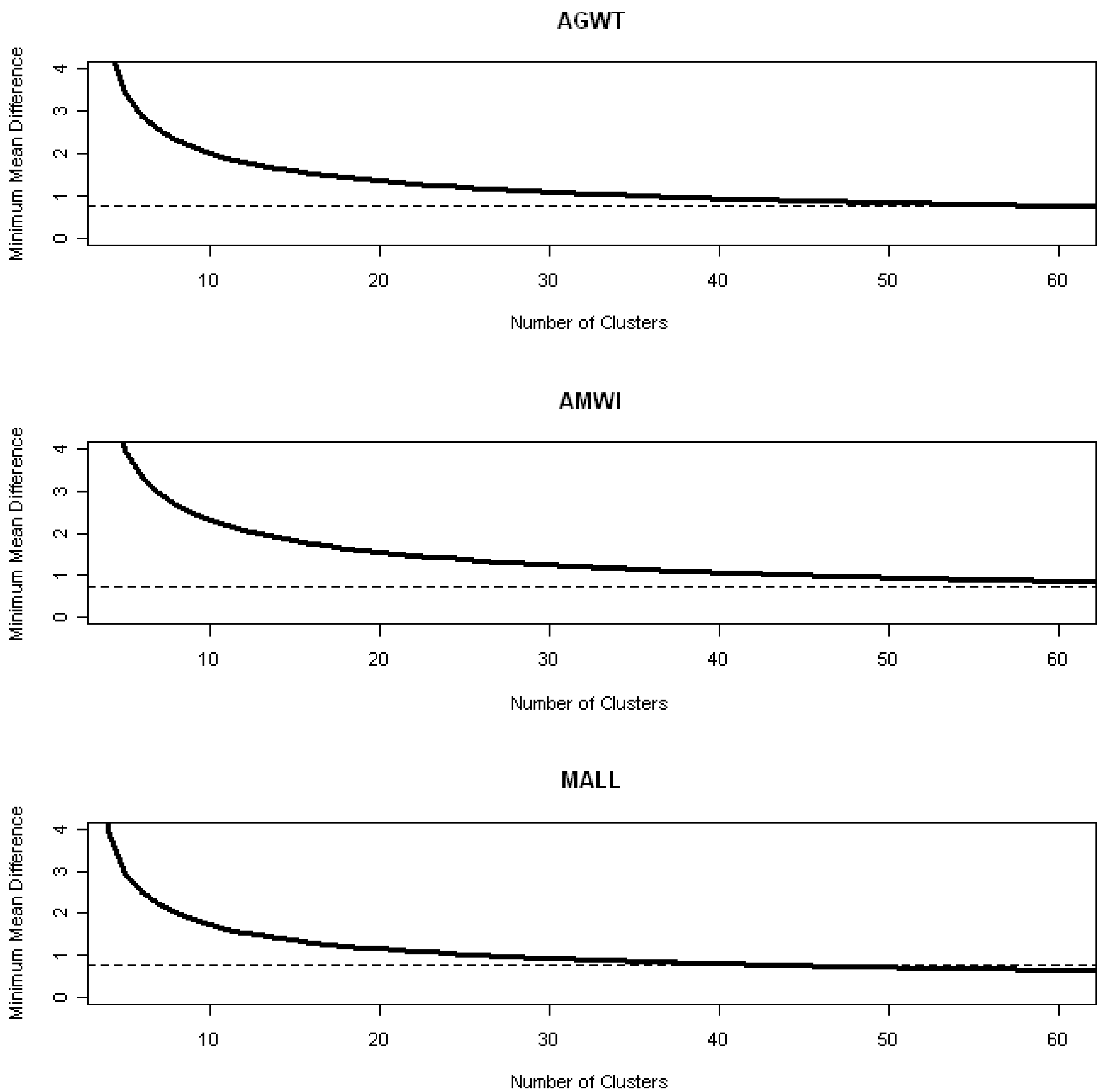

Figure 25b. Divers

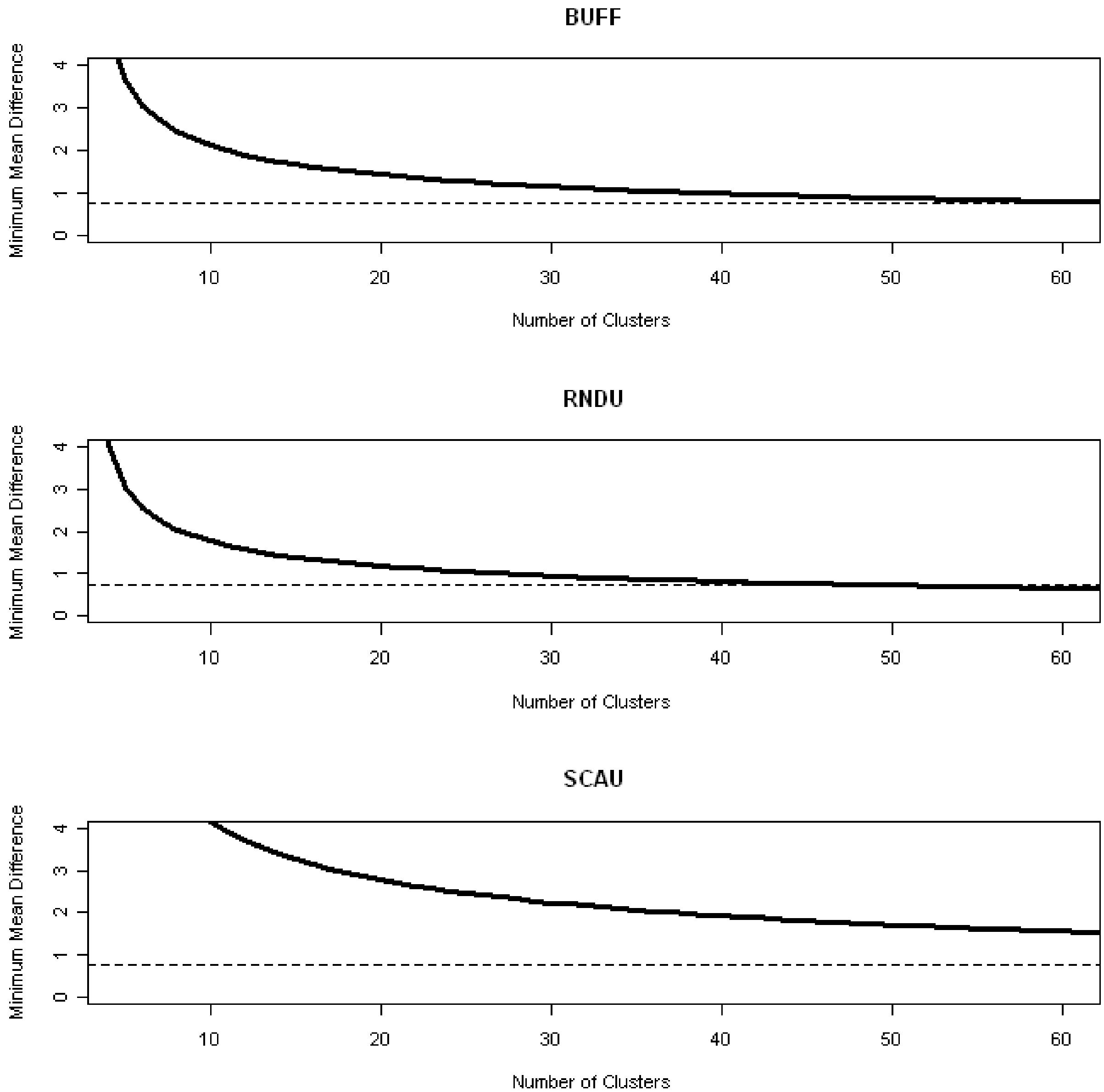

Figure 26. Number of clusters (horizontal axis) required to yield a desired minimum detectable difference between two years in the mean number of broods per water acre. A dashed line has been added at a minimum detectable difference of 0.0075. See Table 1 for observed mean number of broods per cluster for each species.
a. Dabblers

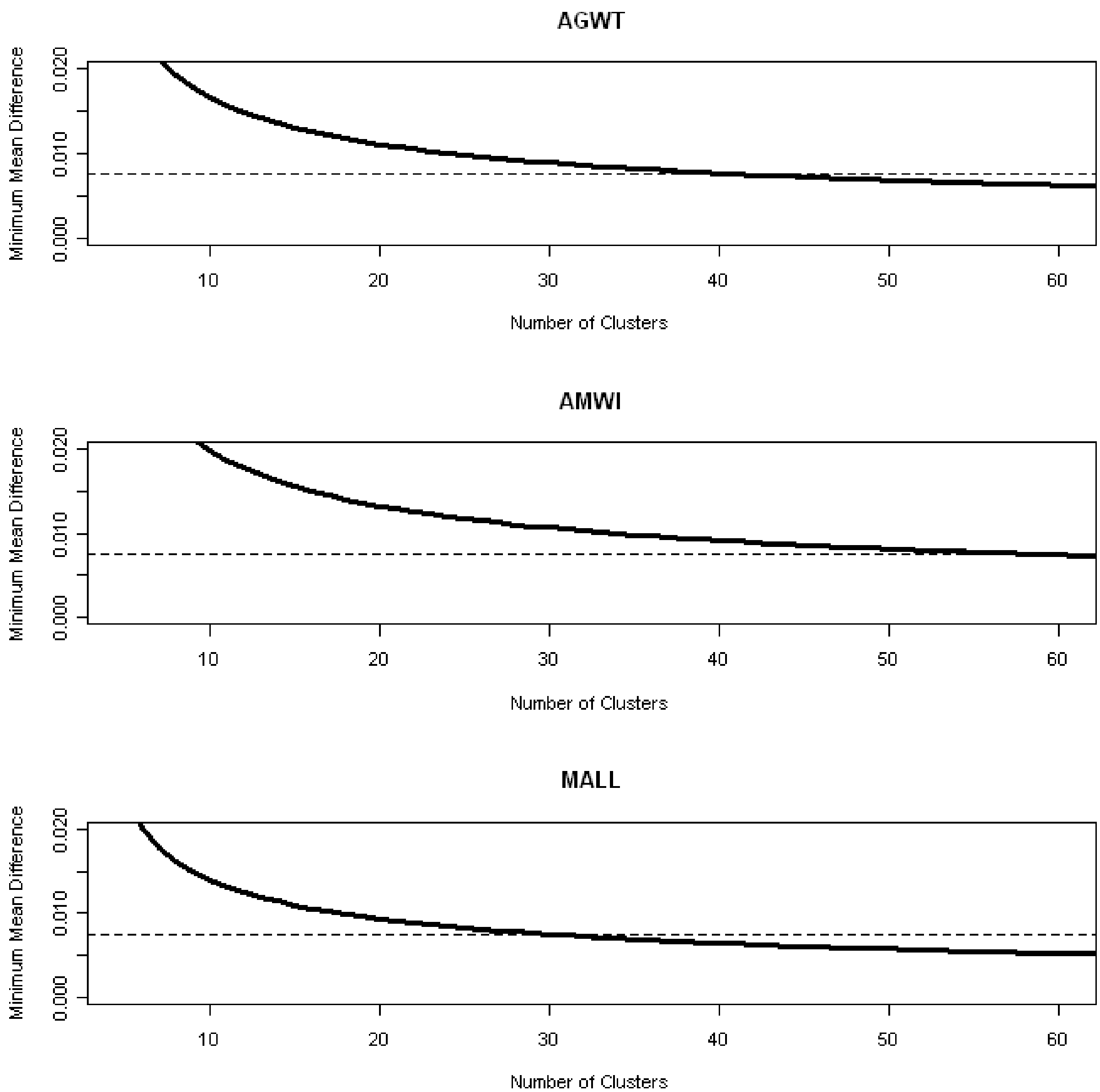

Figure 26b. Divers

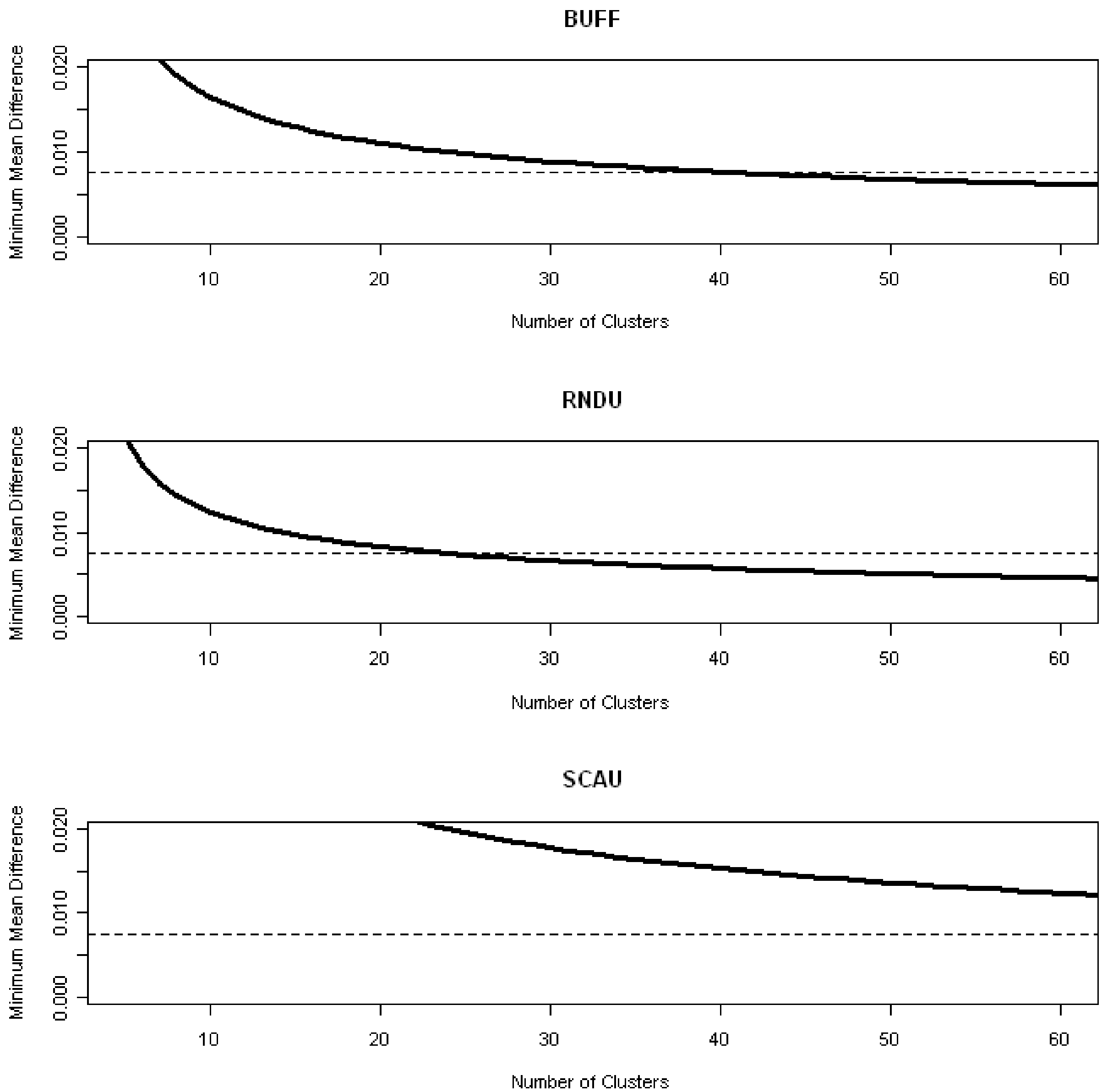

Figure 27. Number of clusters (horizontal axis) required to yield a desired minimum detectable difference between two years in the mean number of broods per water body. A dashed line has been added at a minimum detectable difference of 0.05. See Table 1 for observed mean number of broods per cluster for each species.

a. Dabblers

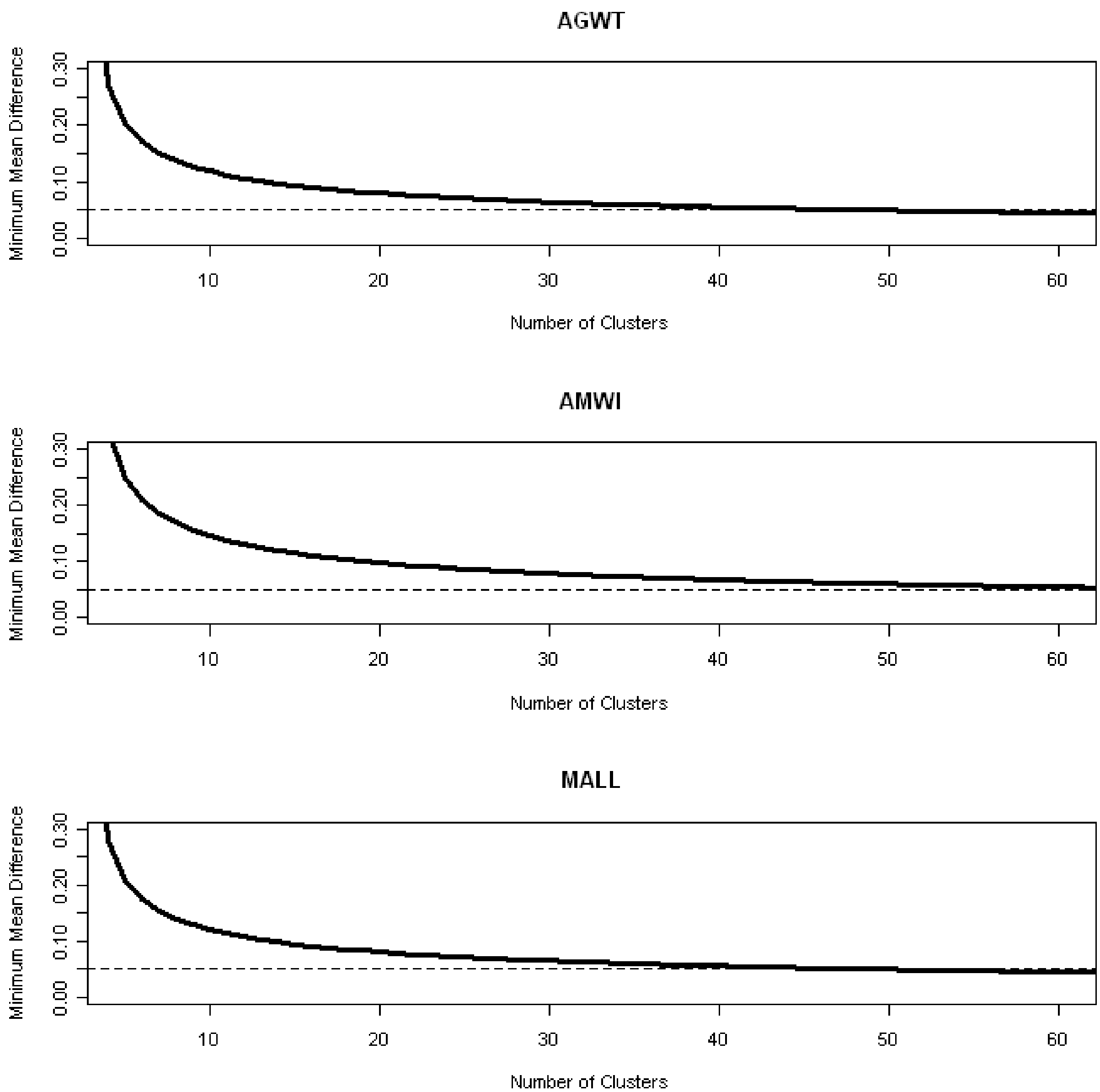

Figure 27b. Divers